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SURVEY OF INTERSTATE POLLUTION OF THE ANIMAS RIVER (COLORADO-NEW MEXICO)

E. C. Tsivoglou, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

May 1959

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COLORADO-NEW MEXICO

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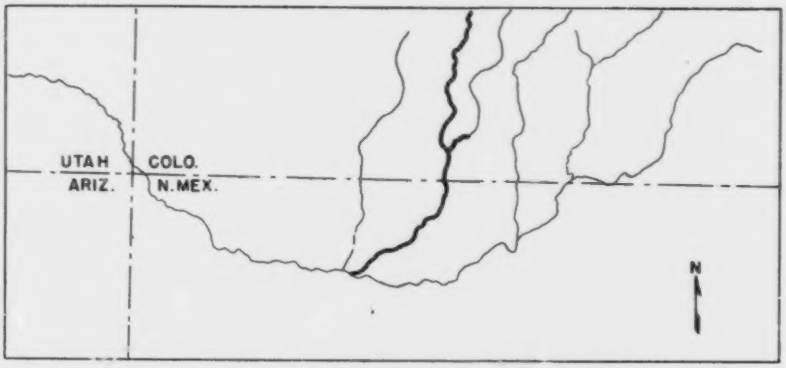

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SURVEY
OF
INTERSTATE POLLUTION
OF THE
ANIMAS RIVER
(COLORADO-NEW MEXICO)

by

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Public Health Service
Bureau of State Services
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Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

May 1959

I-a

FOREWORD

These studies of pollution problems of the interstate waters of the Animas River were performed under the provisions of the Federal Water Pollution Control Act of 1956. Their purpose was to measure the extent of radioactive, chemical, organic, and bacteriological pollution, and the effects of pollution on existing legitimate uses of the interstate waters.

The studies were conducted by personnel of the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, Region VII, Dallas, Texas, and Region VIII, Denver, Colorado, Public Health Service, and with the cooperation of:

State of Colorado Department of Public Health
New Mexico Department of Public Health
State of Colorado Department of Game and Fish
San Juan Basin Health Unit, Durango, Colorado
San Juan County Health Department, Farmington, New Mexico
U. S. Atomic Energy Commission
U. S. Geological Survey
Vanadium Corporation of America

The cooperation and contributions of the following are gratefully acknowledged: R. W. Balliger, V. R. Bickel, J. E. Campbell, J. B. Cohen, D. H. Flora, W. Griffin, G. L. Harlow, C. Henderson, C. R. Hirth, A. B. Joseph, H. L. Krieger and Radiochemical Analysis Group, D. Lemons, J. A. Maxwell, S. May, R. McDonald, F. M. Middleton, D. D. Monaco, G. Murthy and Milk Analysis Group, E. A. Pash, D. E. Rushing, C. N. Shadix, E. C. Tabor, R. Vesper, R. L. Wortman, and operating personnel of the water treatment plants at Aztec, Farmington, and Shiprock, New Mexico.

The efforts of Ann C. Engbersen and Eloise C. Webb in the preparation of this manuscript are appreciated.

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SECTION I

INTRODUCTION AND BACKGROUND

This interim report of studies of pollution of the Animas River is made in keeping with the recommendations of the first session of the conference on interstate pollution of the Animas.(1) That meeting was held at Santa Fe, New Mexico, on April 29, 1958, under the provisions of the Federal Water Pollution Control Act. At that time there was available very little technical information regarding the extent and effects of pollution. As a result, the amount of radiation exposure in the Durango-Farmington area could not be estimated within acceptable limits. Accordingly, it was agreed that a fact-finding survey having the following objectives should be performed without undue delay

(a) To evaluate the internal radiation exposure to radium and strontium-90 in the Durango-Farmington population area, and the portion of this total exposure that results from radium and other waste discharges from the Vanadium Corporation of America uranium refinery at Durango, Colorado.

(b) On the basis of the above evaluation, to assess the interstate pollutional aspects of the uranium refinery waste discharges.

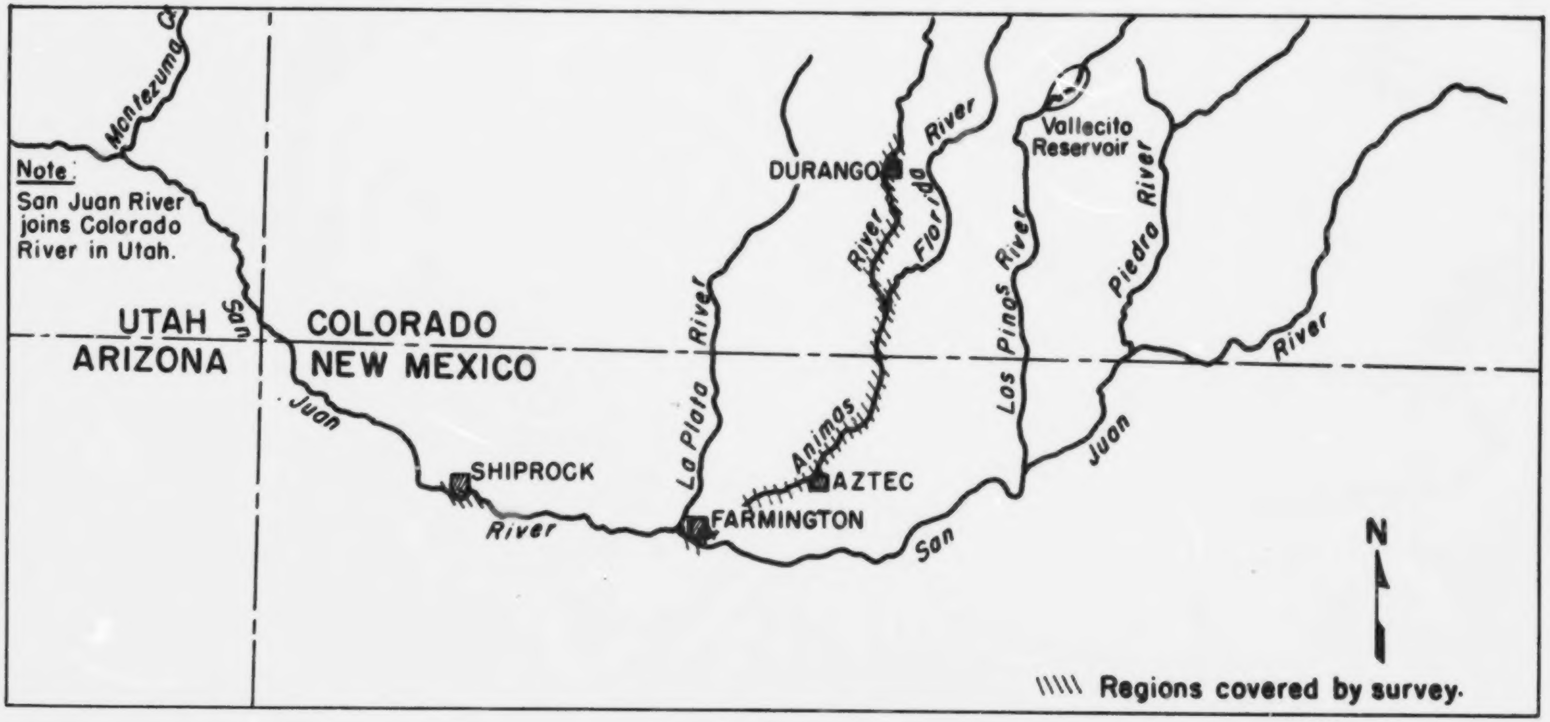
The fact-finding survey was begun in July 1958, and was planned to include a period of one year. It has been a cooperative effort of the Public Health Service, the State Health Departments of New Mexico and of Colorado, the San Juan Basin Health Unit of Colorado, the San Juan County Health Department of New Mexico, the U. S. Atomic Energy Commission, and the Vanadium Corporation of America. During the summer of 1958 an intensive field survey of the river and local environment was carried out by a crew of six technical personnel from the Public Health Service, with the aid of the State and local health agencies. Excellent laboratory facilities of immeasurable aid in the studies were made available during this time at Farmington, New Mexico, by the San Juan County Health Department. During this same period a brief intensive survey of the uranium refinery as a waste source was performed with the cooperation of Vanadium Corporation of America personnel. Environmental samples obtained during this period also reflected any local radioactive fallout resulting from nuclear weapons tests.

This report includes primarily the data obtained from the intensive field studies of the summer of 1958. However, following the summer field survey, certain samples were collected on a routine basis through the first half of 1959 by the State and local health agencies, and shipped to the Public Health Service for analysis. Because of the large numbers of samples involved and the variety of analyses required, it has not been possible to complete analysis of the later samples at this time. They are in process, and a further report covering the full year of survey will be prepared as quickly as possible. However, it is believed that the data now available are reasonably sufficient to satisfy the primary objectives set forth above.

Locale of Survey and Water Uses

Figure 1 is a map indicating the general locale and extent of the environmental surveys. The Animas rises in rugged mountains in the vicinity of Silverton, Colorado. It proceeds south from there some 50 miles to Durango, Colorado, and joins the San Juan River about 60 river miles south and west of Durango, at Farmington, New Mexico. North of Durango the terrain is mountainous and the river valley quite narrow, while to the south the country is less rugged and becomes more suitable for farming. Precipitation is markedly reduced in the New Mexico reaches, and the San Juan Basin below Farmington is relatively arid. The primary survey area included some 60 miles of the Animas River, from a location above Durango to the confluence with the San Juan. In addition, limited sampling was undertaken near Silverton, Colorado, and near Shiprock, New Mexico, on the San Juan. A detailed map is presented in Figure 2, and indicates locations of sampling stations, sources of pollution, and other pertinent information.

The Animas near Durango and downstream is used for a variety of purposes. It serves as a source of domestic water supply for Aztec and Farmington, New Mexico, with populations of approximately 6,000 and 22,000 people, respectively. Durango obtains its water supply for its 11,500 people from the upper Florida River, which is the only major tributary of the Animas, and which lies wholly in Colorado. In addition to these treated community supplies, Animas River water is used in its raw state south of Durango by approximately 100 people in Colorado and by an estimated 1,845 people in New Mexico. (2) These individual users have a variety of collection and storage devices, some taking water direct from the Animas and others from irrigation ditches carrying Animas River water; some simply store the water, untreated in any fashion, in cisterns, while others employ cisterns preceded by filters. Below Farmington, an estimated 2,310 persons use the San Juan River as a source of raw water supply,(2) and Shiprock obtains its municipal supply from the San Juan.


Montezuma Cr.
Note:
San Juan River
joins Colorado
River in Utah.
UTAH
ARIZONA
COLORADO
NEW MEXICO
San
Juan
River
SHIPROCK
La Plata River
FARMINGTON
AZTEC
Animas River
DURANGO
Florida River
Los Pinos River
Vallecito
Reservoir
Piedra River
San
Juan
River
N
\\\\\ Regions covered by survey.

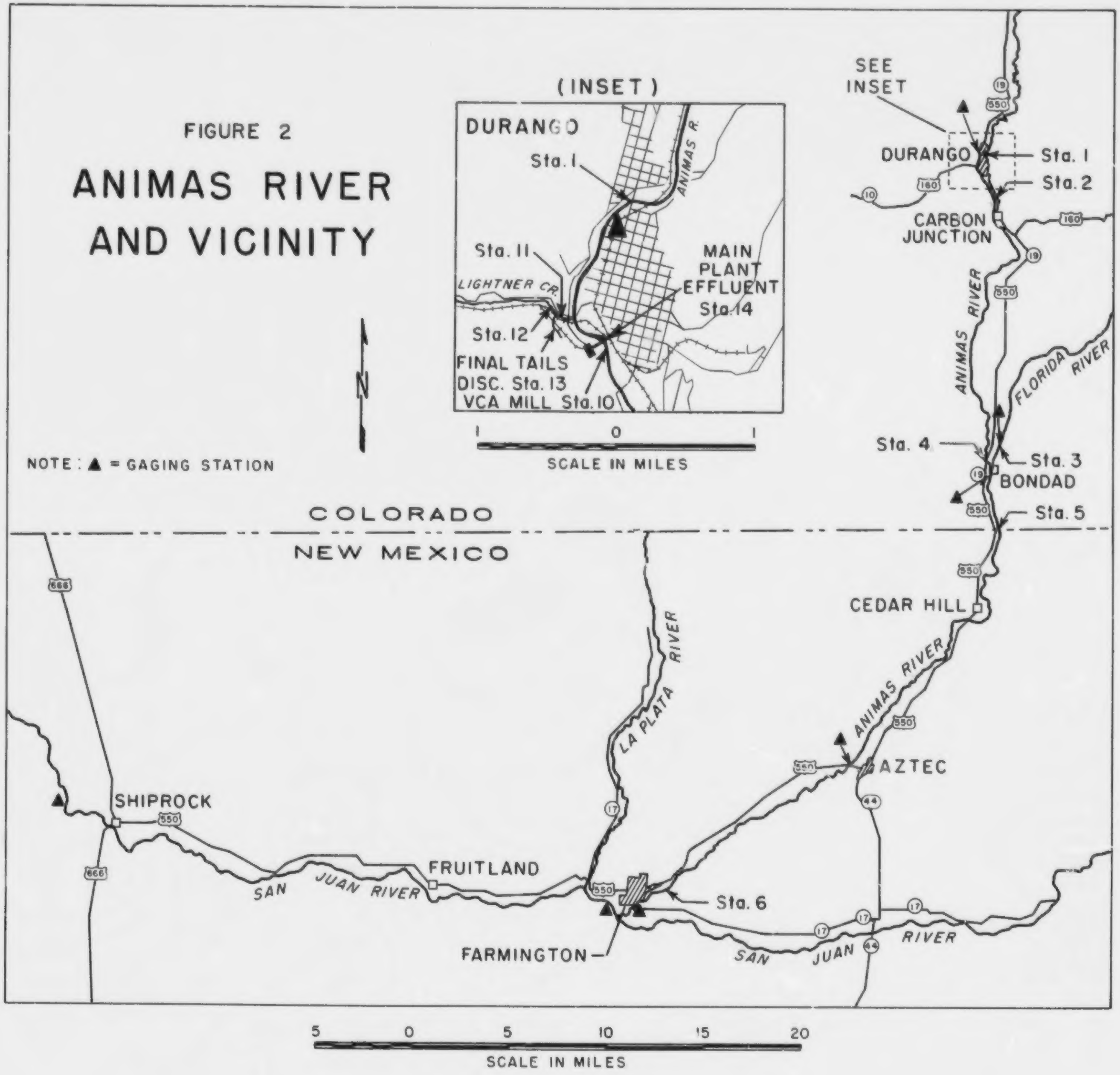
GENERAL LOCALE MAP
ANIMAS RIVER

10 0 10 20 30 40
MILES

FIGURE I

FIGURE 2

ANIMAS RIVER AND VICINITY


(INSET)
DURANGO
Sta. 1
ANIMAS R.
Sta. 11
LIGHTNER CR.
MAIN PLANT EFFLUENT Sta. 14
Sta. 12
FINAL TAILS DISC. Sta. 13
VCA MILL Sta. 10
1 0 1
SCALE IN MILES
N
NOTE: ▲ = GAGING STATION
SEE INSET
DURANGO
Sta. 1
Sta. 2
CARBON JUNCTION
ANIMAS RIVER
FLORIDA RIVER
Sta. 4
Sta. 3
BONDAD
Sta. 5
COLORADO
NEW MEXICO
CEDAR HILL
ANIMAS RIVER
AZTEC
LA PLATA RIVER
SHIPROCK
FRUITLAND
SAN JUAN RIVER
Sta. 6
FARMINGTON
SAN JUAN RIVER
19
550
160
10
666
17
44
64
5 0 5 10 15 20
SCALE IN MILES

Below Durango the Animas provides water for several irrigation ditches which provide water to irrigate some 26,000 acres of croplands above Farmington. An additional 36,000 acres between Farmington and Shiprock are irrigated with waters of the San Juan. A wide variety of crops, including root and leaf vegetables, cereals and grains, and fruits is grown in the area, and these will be detailed in later Sections.

The river below Durango also serves as a recreational area, and is used to some extent for swimming and fishing. Fishing in and immediately above Durango is prevalent. A State fish hatchery is located in Durango, and fish from this hatchery are used to stock the river. Both fishing and swimming were observed during the 1958 survey at a location only a few hundred yards below the Durango uranium refinery, on the opposite side of the river and towards its center.

Downstream from Durango the Animas is used also for stock watering, both directly and via the irrigation ditches. It also serves as a source of industrial process water supply for the Vanadium Corporation of America mill, and carries away the waste discharges from this ore refinery as well as from the City of Durango and sundry other small sources.

Thus, the Animas is a vital natural resource of the area.

Prior Data

The uranium refinery at Durango has been in continuous operation since 1948.(4) In 1950, at the request of interested States, samples of river water were collected at locations above and below several uranium refineries, of which the Durango mill was one.(5) These samples were analyzed for dissolved radium. The analytical results are noted in Table I, and are discussed below.

In the fall of 1955 a second brief survey was performed on streams in the vicinity of eight operating mills.(6) The Durango mill was included. At this time samples of river water, bottom mud, and biota (algae, insects) were collected at locations immediately above and below the mill and analyzed for gross radioactivity and for radium. Samples of the effluents from the mill were also collected and analyzed at this time. Results are given in Table I for the water samples and effluents, and in Table II for the mud and biological samples, and will be discussed below.

The effluents from the mill were at quite small flow rates at the time of the 1955 survey; hence, although their radioactivity was high relative to the natural stream radioactivity, the dilution effect was great, as indicated by the results obtained at the downstream sampling point. Both the 1950 and the 1955 sampling runs indicated a gain in the dissolved radium content of the river by a factor of about 20.

The biological and mud samples taken in 1955 are cumulative as contrasted with the instantaneous samples of flowing river water. Rather they

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Table I

Radioactivity of Water Samples

(Animas River near Durango, Colorado)

Location	Radioactivity, μμc/l.						Diss.
	Gross Alpha			Gross Beta			Radium
	Susp.	Diss.	Total	Susp.	Diss.	Total	
1950							
Animas River Above Mill	---	---	---	---	---	---	0.20
Animas River Below Mill	---	---	---	---	---	---	4.5
1955							
Animas River Above Mill	2	0	2	4	28	32	0.2
Animas River Below Mill	7	27	34	22	4	26	3.3
Direct Effluent From Mill	33,200	10,000	43,200	2,300	14,000	16,300	76
Tailings Pond Effluent From Mill	300	2,900	3,200	2,300	5,200	7,500	25

represent some unknown period of accumulation of radioactive material discharged from the mill. These data indicate a gain by a factor of about 100 in the radium content of the stream biota. Radium was not determined at this time for the mud samples.

Flows in the Animas River at Durango were 250 cfs in 1955 and 220 cfs in 1950 at the time of sampling. These data indicated an approximate discharge of 2.0 milligrams per day of dissolved radium from the Durango refinery.

Table II

Radioactivity of Mud and Biological Samples, 1955

(Animas River near Durango, Colorado)

Location	Radioactivity, μμc/gm.							
	Mud		Algae			Bottom Insects		
	Gross Alpha	Gross Beta	Gross Alpha	Gross Beta	Radium	Gross Alpha	Gross Beta	Radium
Animas River Above Mill	16	71	85	200	6	100	260	6
Animas River Below Mill	850	550	2,600	8,600	660	1,500	4,800	360

The results of the 1950 and 1955 surveys cannot be considered as representative of any long period of time. They represent only isolated samples and cannot be accepted, for example, as average results for any extended period. In addition, while collection methods for the 1950 data are not known, it can be said that the 1955 samples were not representative of the river cross section below the refinery. These samples were collected a few hundred yards below the industry on the opposite side of the river. Data to be presented later indicate clearly that the mill effluents are only partially mixed in the river at this point, and hug the mill side of the river well below the sampling location. As a result, the samples collected in 1955 most probably yielded data lower than the actual situation. Nevertheless, the data did indicate a definite gain in stream radioactivity below the mill.

Radiation Exposure and Existing Standards

Radioactive materials that are ingested or inhaled result in internal radiation exposure, as contrasted to the external exposure resulting from a source of penetrating radiation located outside the body. On ingestion, certain radioelements tend to accumulate in specific body organs - for example, radium and strontium accumulate in the bones, while iodine goes to the thyroid gland. Such radioactive materials irradiate the surrounding tissue until they have decayed or have been biologically eliminated. As regards radioactive wastes from the Durango uranium mill, we are concerned with internal radiation exposure of the local population, and the remainder of this statement considers only internal exposure.

It is important to distinguish between "natural" or "background" radioactivity, and that which is added artificially as pollution. Natural waters have always contained a small amount of radioactivity, entirely derived from radioelements such as uranium, thorium, radium, and potassium-40 that occur naturally in the earth's crust.(7) Although there are few exceptions such as certain hot springs, this natural radioactivity of surface and ground waters is generally considerably less than the permissible amount. (See below, Maximum Permissible Concentrations.) The background radioactivity of the Animas River is similar - for example, its dissolved radium content is no more than 10 per cent of the permissible amount (See Table I). Since the advent of nuclear weapons testing there has been a general increase in the radioactivity of the environment. Nuclear industry such as uranium refineries or atomic power plants may further add to local environmental radioactivity by discharging radioactive wastes.

In determining criteria for the safe disposal of radioactive wastes it is important to consider all means by which the local population group is exposed to radiation. The effects of radiation exposure are cumulative, and the total exposure of a population is much more significant than the fraction of it associated with one particular source such as drinking water. An individual or a community may drink slightly contaminated water and milk, eat slightly contaminated food, and breathe slightly contaminated air. A portion of the individuals may during their working hours inhale or ingest somewhat higher amounts of radioactive materials as a result of their occupation in the nuclear industry. It is the total exposure that has real significance, and it is important to examine each source, such as a domestic water supply, in the light of the total radioactivity intake from all local sources. While any individual exposure, such as that from the domestic water supply, may be lower than the maximum allowable, the total radiation exposure from all sources may exceed that regarded as safe.

In addition to the local sources of exposure, one must consider the human intake of radioactive materials that are distributed by nuclear weapons testing. The resulting fission products are distributed into the air, soil, water and all phases of the environment. The regional distribution of these materials is dependent upon frequency of weapons tests, location of the test site, local and general meteorological conditions, and other factors. Although many radioelements are so distributed, our concern here is mainly with radioactive strontium, because its behavior and effect is similar to that of radium.

Maximum Permissible Concentrations

National Bureau of Standards. Maximum Permissible Concentrations (MPC's) in air and in domestic water supply for most radioelements are listed in Handbook 52, National Bureau of Standards,(8) and these are the basic recommendations of the National Committee on Radiation Protection for protection against excessive internal radiation exposure. An addendum(9) to Handbook 59, National Bureau of Standards, indicates that the concentrations listed in Handbook 52 represent allowable internal exposure for radiation workers, and should have a safety factor of ten applied for protection of the general population outside the controlled area, or industrial site. These MPC's refer to the amount of any listed radioisotope that can be ingested in domestic water supply continuously over a lifetime without producing any readily detectable biological damage.

Radium is a long-lived alpha emitter that deposits in the bones. It decays successively to several other elements, or daughters, that are also radioactive. The MPC for radium plus one-half of the equilibrium amounts of its radioactive daughters in public water supply is 4 micromicrocuries per liter (μμc/l). This is the lowest of all of the MPC's listed in Handbook 52 for domestic water supply and in these terms radium is considered the most hazardous of all of the listed radioisotopes.

Strontium-90 also decays to a radioactive daughter, yttrium-90, and the MPC for strontium-90 plus an equilibrium amount of yttrium-90 in domestic water supply is 80 μμc/l. Strontium is also relatively long-lived, emits beta particles during decay, and deposits primarily in the bones. It has next to the lowest of all of the Handbook 52 MPC's in domestic water supply, being second only to radium in this regard.

The basic principle of protection against internal radiation exposure is to place an upper limit on the amount of exposure that can be allowed for the affected organ. This has the effect of placing an upper limit on the total allowable intake of any particular radioisotope. Thus, if radium were the only radioisotope involved here, and if the domestic water supply were the only means of human intake, then the domestic water supply could allowably contain as much radium as is specified by its MPC. If, however, radium is ingested via several paths such as domestic water supply and crops that have radium in them, then the total intake of radium must be considered. Thus, if the crops contained a relatively large quantity of radium, the content of the water supply would have to be severely limited, at some level well below the MPC. Conversely, if the domestic water supply were to contain the maximum permissible amount of radium, then intake via other paths such as food would result in exceeding the safe radiation exposure.

The same principles apply to combinations of radioisotopes that affect the same organ. To quote Handbook 52: "Often a person is subject to radiation exposure from several different sources simultaneously. In any case, the maximum permissible concentration of radioisotopes in air and water and the external radiation should not exceed values that will permit an exposure of 0.3 rem/week to any part of the body except the epidermal skin layer." Thus, because radium and strontium both affect the bones, they must be considered together as a source of internal radiation exposure, and the allowable intake of one is directly affected by the presence of the other. For example, if a domestic water supply were to contain the maximum permissible amount of strontium-90 then no radium could be permitted in it, and vice versa; or, if the water supply contained half of the MPC of strontium-90, then only half of the radium MPC could be allowed. The intake of either of these radioelements by other paths such as food or milk would further restrict the allowable intake via the domestic water supply.

Finally, in regard to the numerical MPC's listed in Handbook 52, the following cautionary statement is presented:

"Because of the many uncertainties involved, this Committee recommends that every effort be made to keep the concentrations of radioisotopes in air and water and in the body to a minimum. The goal should be no radioactive contamination of air and water and of the body if it can be accomplished with reasonable effort and expense. If such a goal cannot be attained, the average operating levels should be kept as far below these recommended values as possible, and not above them for any extended periods of time."

U. S. Atomic Energy Commission. In January 1957 the U. S. Atomic Energy Commission published its Standards for Protection Against Radiation(10) including standards to be applied in the case of private individuals or companies licensed by the Commission to possess or use radioactive materials. The Vanadium Corporation of America refinery at Durango, Colorado, is such a licensee. In brief, as regards radium, the basic standard requires that effluents to unrestricted areas contain no more than 4 micromicrocuries per liter of radium plus one-half of the equilibrium amounts of its radioactive daughters. This refers to an effluent concentration before dilution in a receiving stream. Upon written application of the licensee, however, the Commission may approve higher limits if the applicant can demonstrate that it is not likely that any individual will be exposed to concentrations in excess of 4 μμc/l. of radium plus one-half of the equilibrium amounts of its daughters. It is further specified that each licensee shall be responsible for making such surveys as may be necessary for him to comply with the above regulations.

As regards allowable concentrations of radioisotopes in food, the U.S. Atomic Energy Commission indicates that the values for specific radioisotopes used for water are also applicable to foods on a wet (live) weight basis. Thus, the allowable concentration of radium in foods is 4 micromicrocuries per kilogram of live material.

SECTION II

HYDROLOGICAL ASPECTS

The availability of river dilution water is an important consideration in estimating the effect of any pollutant on legitimate uses of a receiving stream. In order to adequately interpret the data obtained in any stream survey it is necessary to be able to predict the effects of pollutants under generally expected conditions of stream flow. With a relatively constant waste discharge, the most serious damaging effects on downstream water use usually occur at low stream flows, or when minimum dilution is available. Under these conditions, although the total quantity of pollutant passing a given point per unit time remains constant, maximum concentrations occur. Hence, it is highly desirable to be able to predict the frequency of occurrence of low flow conditions. Such predictions are based upon statistical analysis of the available stream flow records, as well as upon information regarding local flow regulation practice, local irrigation practice, plans for future stream flow regulation, and other pertinent circumstances.

Stream flow records for the Animas River at several gaging stations have been maintained at least intermittently since 1895, and the data are available in publications of the U. S. Geological Survey.(11) Continuous records are available for the period October 1, 1934, through September 30, 1956, for stream gaging stations at Durango, Cedar Hill, and Farmington on the Animas River and at Farmington and Shiprock on the San Juan. It is this uninterrupted flow record that has been used for these studies, as well as limited data for the Florida River at Bondad, Colorado. These data were supplemented by copies of the stage-recorder charts for the water year October 1, 1957, through September 30, 1958, which included the period of the 1958 summer field survey. Data for the water year ending September 30, 1958, while adequate for these purposes, must be considered as provisional until officially published by the U. S. Geological Survey. As an illustration of the river flow pattern at Durango, a typical daily hydrograph for that location in shown by Figure 3.

In addition to the above available data, flow records for the Animas River at Aztec, New Mexico, were obtained on a temporary basis by the U. S. Geological Survey, which established a wire-weight gage at Aztec specifically for these studies. This gage provided supplementary information on stream flow between the Cedar Hill and Farmington locations.

Because it provides the most dependable record, essentially unaffected by irrigation water use, the flow record at Durango, Colorado, has been selected as a control in the hydrologic studies, and the continuous 1934-1956 record utilized. All of the data presented in the frequency analysis were compiled in a fashion to correlate with that station.

Existing upstream regulation of flow and irrigation practice has negligible effect upon the Animas River flows at Durango. As will be seen, by the time the river reaches Farmington,its flow pattern during droughts has been materially altered by upstream irrigation practice. The effects of construction and operation of the Navajo Dam on the San Juan River and of the proposed Animas-La Plata Diversion project on the Animas River have not been included here because detailed data as to these projects were not available. Present information indicates that these projects, when completed, will divert considerable flow from the rivers involved, and will leave only minimum flows required to satisfy existing water rights and to maintain fish life. This would materially reduce the available dilution at Durango.

Table III presents pertinent information regarding the individual stream gaging stations.

Because of the lack of flow regulation above Durango, the general stream flow patterns at that location have not changed significantly during the period of record. This is seen from analysis of the average annual discharge data as well as from the pattern of occurrence of low flows.

Flow Frequency Studies

Several methods of analysis of stream flow data are available for estimating return periods for low flows, or low flow frequencies. They include simple as well as relatively complex statistical procedures. In order to obtain the best possible estimates of flow frequencies, all of the applicable methods were utilized, including arithmetic, arithmetic probability, logarithmic probability, and Gumbel-type(12) curve fitting techniques. There was quite good agreement obtained by the several methods of analysis. Factors such as irrigation water withdrawal and freezing resulted in occasional statistically unsatisfactory extremums. In such instances rational use of the several curve fitting techniques permitted the best choice of low flow return periods. Figures 4 through 7 provide examples of the several

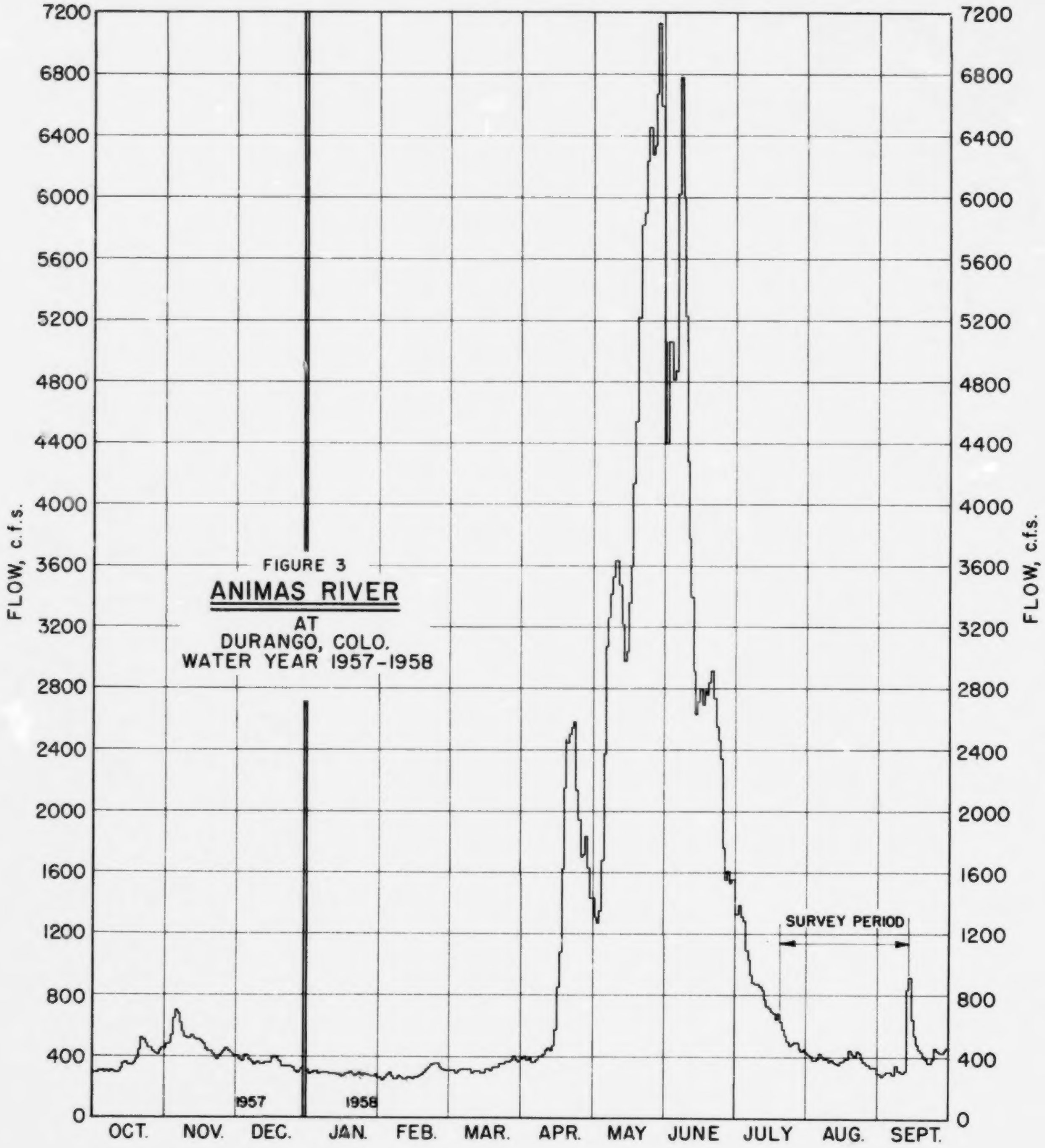
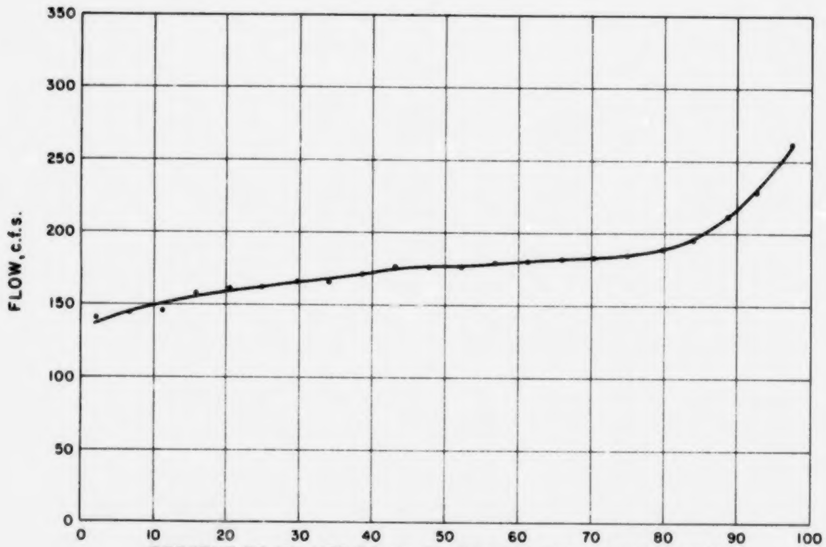


FIGURE 3

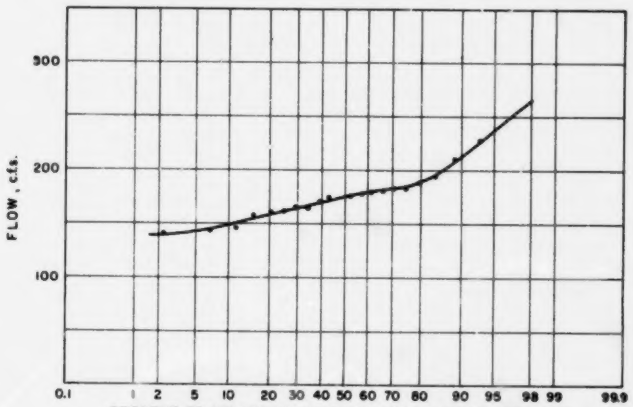
ANIMAS RIVER

AT
DURANGO, COLO.
WATER YEAR 1957-1958



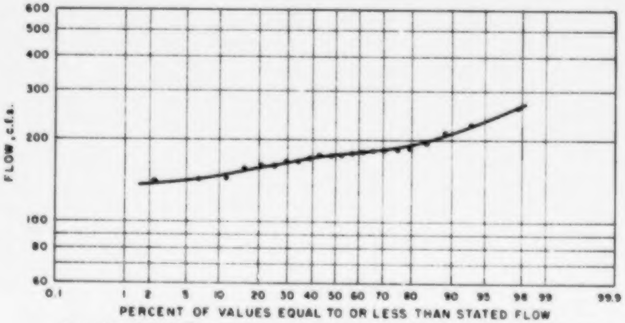
ANIMAS RIVER @ DURANGO - FREQUENCY DISTRIBUTION OF MINIMUM MONTHLY AVERAGE FLOWS - 1935-56

FIGURE 4



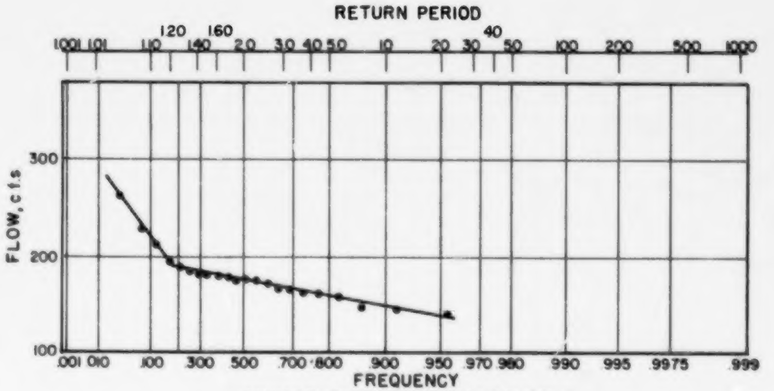
ANIMAS RIVER @ DURANGO - FREQUENCY DISTRIBUTION MINIMUM MONTHLY AVERAGE FLOWS-1935-56

FIGURE 5



ANIMAS RIVER @ DURANGO - FREQUENCY DISTRIBUTION OF MINIMUM MONTHLY AVERAGE FLOWS - 1935-56

FIGURE 6



ANIMAS RIVER @ DURANGO, COLO.
MINIMUM MONTHLY AVERAGE FLOW
1935-1956

FIGURE 7

COURTESY OF:
E J GUMBEL

Table III

Stream Gaging Stations *

Location	Drainage Area Sq.Miles	River Miles From Durango	Acres Irrigated Above	Continuous *** Flow Record Available
Animas River				
Durango	692	0	4,000	1935-56
Cedar Hill	1,090	25	20,000	" "
Farmington	1,360	61	30,000	" "
San Juan River				
Farmington **	7,240	62	86,000	" "
Shiprock	12,900	94	118,000	" "

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* Additional survey period records were obtained at Aztec, New Mexico, and for the Florida River at Bondad, Colorado.

** Includes flow of Animas River at Farmington.

*** These refer to water years, which begin on October 1 and end on September 30.

types of analysis applied to the data. They are for the case of minimum monthly average flows at Durango, for the period 1935-56.

The results of these analyses are presented in Table IV. For example, the record at Durango indicates that the average flow for the entire period was 781 cubic feet per second (cfs); minimum daily average flows for each year ranged from 110 to 212 cfs, with an average of 145 cfs; minimum monthly average flows have ranged as low as 141 cfs and as high as 261 cfs, with an average for the 21-year record of 179 cfs. Flow frequency studies indicate that a minimum monthly average flow as low as 175 cfs may be expected to occur on the average once every two years; a minimum monthly average flow as low as 148 cfs is expected to occur on the average once every ten years. Put another way, over a 30-year period a minimum monthly average flow as low as 148 cfs will probably occur three times; a minimum monthly average flow as low as 175 cfs will most probably occur 15 times. Such studies are statistical in the sense that nothing can be predicted about the particular year in which a specific flow will occur. Thus, a minimum monthly average flow of 148 cfs will not occur every tenth year, but rather can be expected on the average in 10 per cent of the years, without specification as to which particular year.

Similarly, the data of Table IV show that minimum daily average flows at Durango as low as 145, and 112 cfs can be expected on the average once in every 2 and 10 years, respectively.

It should be noted that the minima given in Table IV do not all occur under the same conditions. At Durango and Cedar Hill the minima normally occur during the cold winter months, whereas the Animas at Farmington has its minimum flow condition predominantly during the warm irrigation season. This frequency of occurrence of minimum flows by months is shown in Figure 8.

Critical Analysis of Animas River at Durango

The data presented above serves to establish relationships between various stations on the Animas River. In order that more detailed information could be obtained for the primary dilution at Durango, additional compilations and computations were made. These additional studies included frequency analyses of all recorded average daily discharges from 1933 through 1956 and minimum 7, 14, and 30 consecutive day average discharges for 1934-56.

Daily average discharges were arrayed in order of magnitude by increments of 100 cfs. From this array a frequency curve, Figure 9, was plotted. Analysis of this curve shows that 50 per cent of the flows during the period of record have been equal to or less than 300 cfs. Flows equal to or less than 200 cfs occurred 20 per cent of the time.

Although values for the minimum daily and monthly average flows are available in published reports, it was desired to obtain more detailed information on intermediate periods for low flow. The values determined were those for 7, 14, and 30-day periods.

The prior noted frequency analyses were based on data published in terms of calendar months. It should be noted that the minimum 30-day flow that occurs in any year probably will not be confined to a single calendar month, but is most likely to extend into two calendar months. For example, such a minimum might occur, say, from August 21 through September 19, and the monthly average flows for August and September would both be greater than the minimum for the 30-day period indicated.

Table IV

Frequency Duration Results

	Animas River, cfs			San Juan River, cfs	
	Durango	Cedar Hill	Farmington	Farmington*	Shiprock
Annual Average Flow:					
Minimum	448	515	407	899	920
Maximum	1311	1713	1699	3739	3855
Average	781	921	837	2235	2323
Median	746	868	761	1878	1964
Minimum Monthly Average Flow/Year:					
Minimum	141	155	11	166	45
Maximum	261	345	292	725	810
Average	179	208	153	408	435
Median	176	200	149	423	469
Expectancy					
1 in 2 years	175	200	150	415	470
1 in 5 years	159	182	90	290	290
1 in 10 years	148	168	52	210	175
1 in 20 years	138	156	16	130	60
Minimum Daily Average Flow/Year:					
Minimum	110	90	2.4	27	8
Maximum	212	270	172	451	590
Average	145	158	72	236	209
Median	146	150	70	243	190
Expectancy					
1 in 2 years	145	157	70	243	205
1 in 5 years	127	130	18	147	50
1 in 10 years	112	111	10	82	19
1 in 20 years	102	94	3	20	9

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* Includes Animas River flow.

It should also be noted that the value for 30-day low flow periods is not always lower than the monthly minimum, owing to several 28 or 29-day months having a lower average flow.

The relationships among these various flow periods are illustrated in Figure 10. Based upon this analysis, the expected low flow frequencies are indicated in Table V.

Table V

Low Flow Frequencies, Durango

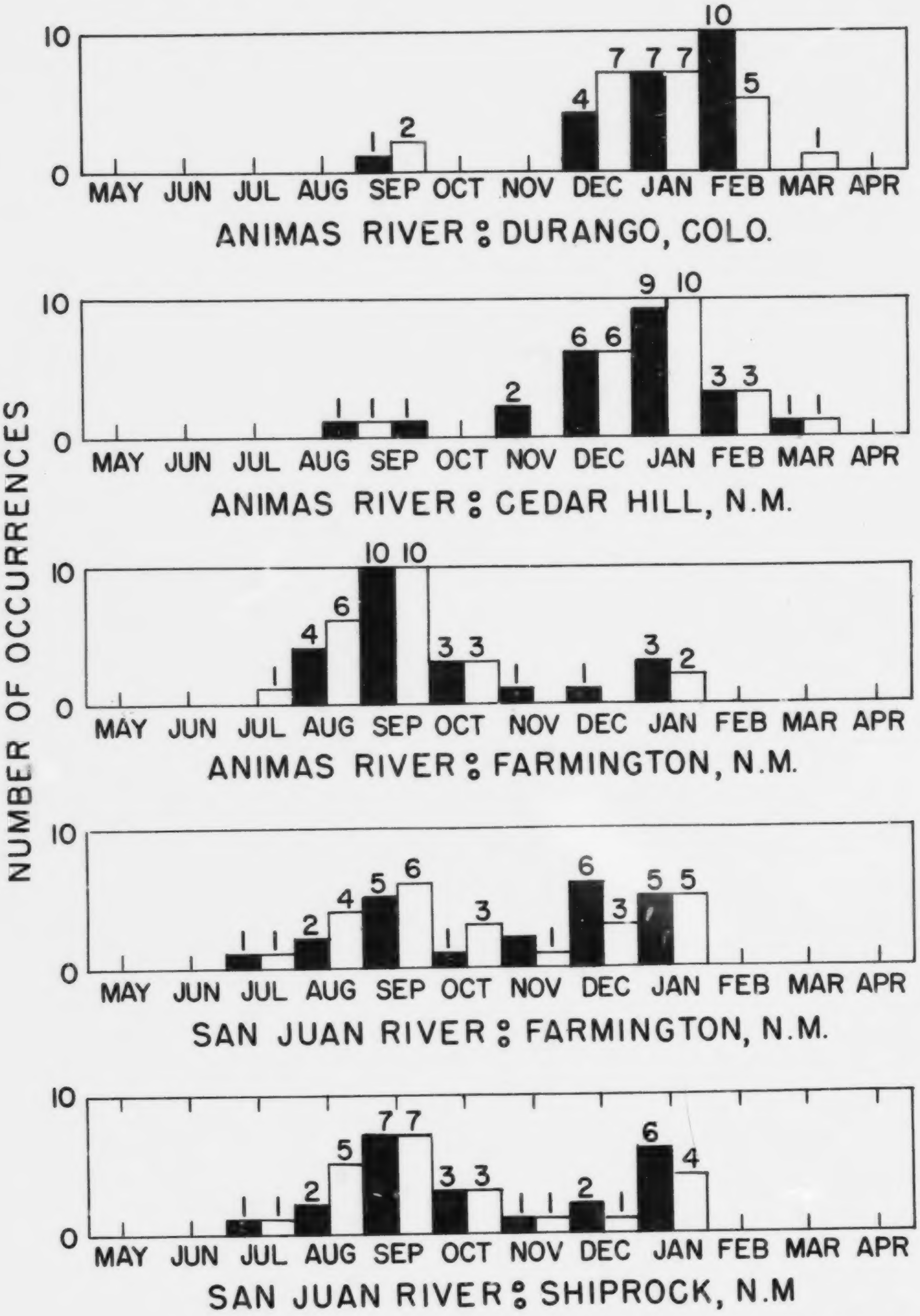
Return Period	Minimum Average Flow, cfs 7 Day	14 Day	30 Day
1 in 2 years	161	165	171
1 in 5 years	142	148	155
1 in 10 years	130	137	144
1 in 20 years	118	126	135

As may be seen by comparison of the data of Tables IV and V, the expected minimum 30-day average flows are only slightly different (lower) from the expected minimum (calendar) monthly average flows noted in Table IV.

Stream Flow During Survey Period

The hydrographs shown in Figure 11 are presented to illustrate the flow rate at the existing gaging stations routinely visited during this survey. In order that analytical data could be correlated, it was necessary to estimate stream flow at the six stream sampling stations based on the available information and knowledge of conditions existing between gaging and sampling stations.

Data for estimation were derived from copies of stage-recorder charts and rating tables for each station. This information was obtained from the U. S. Geological Survey and State of Colorado. It should be noted here that, although these data are provisional, they serve to provide a good basis for estimation. Differences owing to estimation of irrigation water withdrawal and return, together with unrecorded runoff, could not be readily ascertained, which is the reason that a number of gaging stations were utilized.

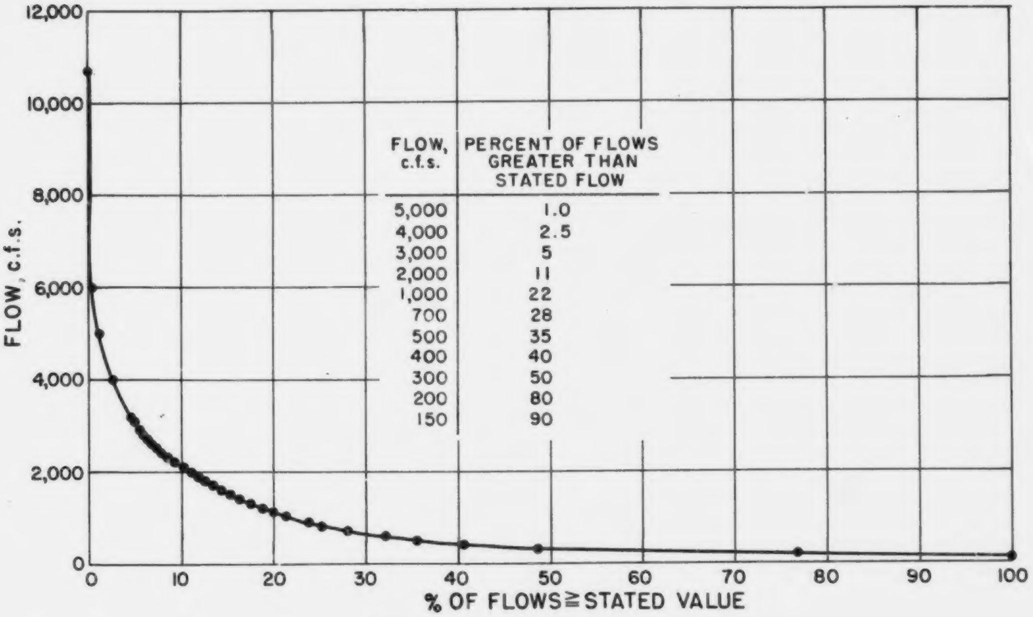


DISTRIBUTION OF MINIMUM FLOW VALUES
BY MONTH OF OCCURRENCE
1935-56

■ MIN. MO. AVER. FLOW
☐ MIN. DAILY AVER. FLOW

FIGURE 8

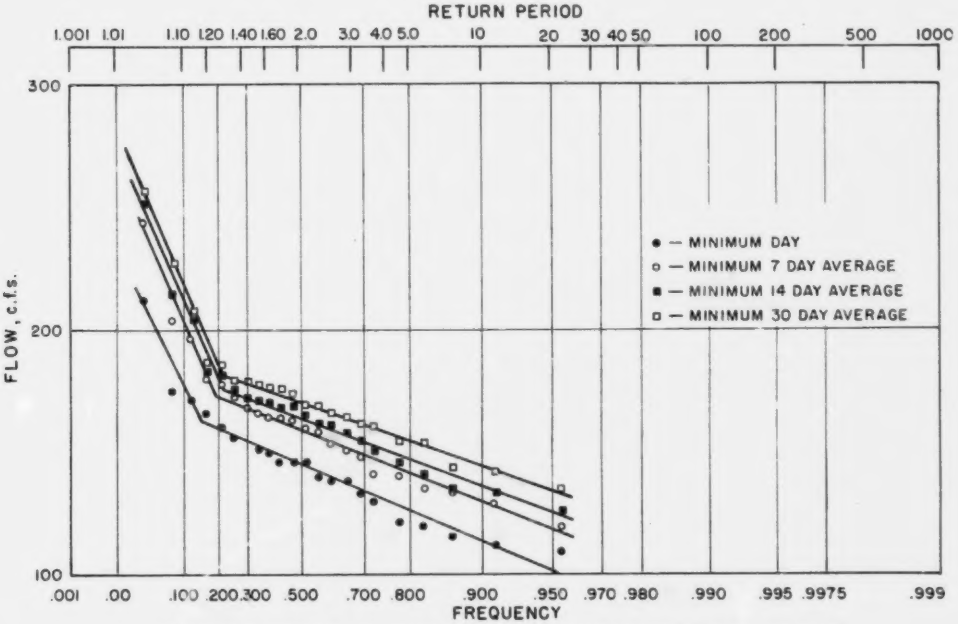
15-a



FLOW, c.f.s.	PERCENT OF FLOWS GREATER THAN STATED FLOW
5,000	1.0
4,000	2.5
3,000	5
2,000	11
1,000	22
700	28
500	35
400	40
300	50
200	80
150	90

ANIMAS RIVER @ DURANGO, COLO.
DISTRIBUTION OF AVERAGE
DAILY FLOWS FOR WATER YEARS 1934-1956

FIGURE 9



ANIMAS RIVER @ DURANGO – MINIMUM AVERAGE FLOWS
WATER YEARS : 1935-56

FIGURE 10

15-b

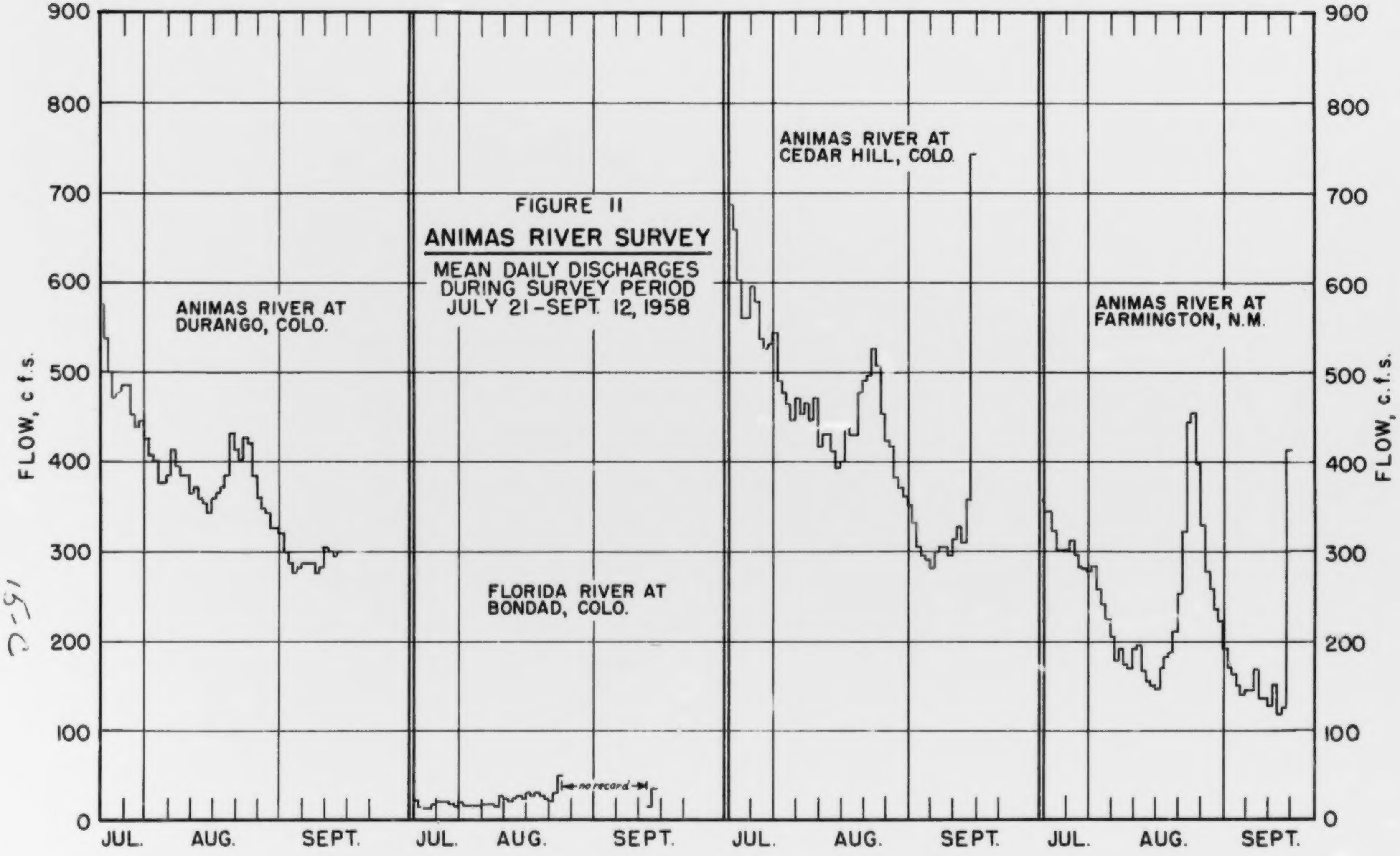


FIGURE 11

ANIMAS RIVER SURVEY

MEAN DAILY DISCHARGES
DURING SURVEY PERIOD
JULY 21-SEPT. 12, 1958

15-C

Table VI

Mean Flow at River Sampling Stations During Survey Period, By Weeks

Sample Sta. No.	Sample Week Mean Flow, cfs							
	1	2	3	4	5	6	7	8
1	500	415	385	360	405	335	290	295
2	505	420	390	365	410	340	295	300
3	17	17	19	25	~30	~25	~20	~20
4	590	495	430	395	450	350	275	300
5	605	510	450	420	480	375	295	320
Aztec	410	380	310	290	370	310	225	210
6	310	270	180	165	330	240	140	130

Table VI indicates the river flows that apply to the specific composite water samples obtained. In determining these values it was necessary to correlate observed flow at the gaging stations with time and type of sample. Both instantaneous and 24-hour composited samples were later composited into weekly samples for analysis. The data of Table VI represent the weighted average flows corresponding to the sampling periods individually, and are therefore not necessarily simple arithmetic averages for the entire sampling period.

Flow data for the Aztec, New Mexico, gaging station were obtained by averaging the wire-weight gage readings for each sampling period. No recorder chart was available for integrating flows, hence these flow data, while adequate, cannot be considered to be as accurate as those for the other locations. Values reported for the Florida River during the period of no record were estimated from previous records and from flows in the Animas River.

Irrigation

As indicated in Table III, there is Animas River diversion for irrigation of only 4,000 acres above Durango, which has but slight effect upon low flow frequencies at Durango. Below Durango, however, where the valley widens out and becomes less rugged, farming is heavier, and between Durango and Farmington sufficient flow is diverted from the Animas to irrigate some 26,000 acres during the growing season. That this has significant effect upon low flow frequencies is evident from Figure 8. There are, between Durango and Farmington, 18 or more separate diversions for irrigation water, with return flows entering the Animas at various locations.

No accurate record of the quantity of water diverted by each ditch is available at this time, but the data of Table IV yield a clear picture of the cumulative effects of diversion and return flow on the low flow expectancies. The major effects of irrigation are reflected between Cedar Hill and Farmington, as shown by comparison of the minimum monthly and daily average flow expectancies at these locations. For example, the minimum monthly average flows expected once in 10 years are 168 and 52 cfs at Cedar Hill and Farmington, respectively. Minimum daily flows of record have been 90 and 2.4 cfs, respectively, with once in 10 year expectancies of 111 and 10 cfs. The Cedar Hill gaging station is located 2.5 miles upstream from the Colorado-New Mexico State line, indicating that the bulk of irrigation diversion represents water for New Mexico farms.

Precipitation

In order to be able properly to interpret the various results of the survey, samples of rainfall were collected during the survey period at both Durango and Farmington. The analytical results will be reported in later sections, but Table VII indicates the dates and quantities of rainfall for the summer survey period.

Rainfall records for the 1958 survey for the Durango vicinity were obtained from the Radio Station KIUP rain gage located at Carbon Junction, about three miles south of Durango, and from the U. S. Weather Bureau rain gage located in Durango. Rainfall records for Farmington vicinity were obtained from U. S. Weather Bureau data for rain gages located at the Farmington Municipal Airport and at a station about four miles northeast of the Farmington Post Office. For this survey rain sample collectors were located on the roof of the San Juan County Health Department Laboratory at Farmington, and at the San Juan Basin Health Unit Building in Durango.

Continuous records of total annual precipitation are available from U. S. Weather Bureau reports for Durango since 1926, for the Municipal Airport at Farmington since 1944, and for the northeast Farmington location since 1933. These records indicate an average total annual precipitation at Durango of 18.36 inches, and at Farmington of 7.37 and 8.02 inches, respectively. The wettest year of record was 1941 at both Durango and Farmington (33.64 and 18.44 inches, respectively) and the driest year of record was 1956, with 10.19 inches, 3.92 inches and 4.44 inches of total annual precipitation at Durango, Farmington Airport and the northeast Farmington station, respectively. Total annual precipitation for calendar 1958, the year of survey, was 16.01, 8.87, and 8.01 inches, respectively, at the three stations. Thus, 1958 was close to an average year for precipitation.

Table VII

Rainfall During Summer Survey, 1958

	Inches of Rainfall			
	Durango		Farmington	
Date	KIUP	USWB	Airport	4 mi. N.E.
July				
17	0.08	-	-	-
18	-	0.14	0.06	0.03
19	-	-	-	0.04
25	0.05	0.03	0.06	-
26	-	-	0.11	-
August				
3	-	0.02	-	-
4	0.15	0.28	0.05	-
5	-	0.14	-	-
7	-	-	0.02	-
9	-	0.48	-	-
10	-	0.03	0.02	-
14	0.39	-	-	-
15	0.04	-	0.08	-
16	-	-	-	0.02
17	0.02	-	0.04	0.03
18	0.18	0.08	-	0.16
19	-	0.35	-	-
21	0.61	0.60	1.68	0.73
22	-	0.09	0.14	0.24
23	-	-	-	0.02
September				
4	-	0.21	-	-
6	-	-	0.20	0.32
7	-	-	0.10	0.11
8	0.18	-	-	0.09
9	-	0.01	-	-
12	0.60	0.37	0.50	0.05
13	0.63	1.07	0.09	0.36
14	-	-	-	0.04
TOTALS:	2.93	3.90	3.15	2.24

As indicated by Table VII, the majority of the rains that occurred during the 1958 survey were local and light, or were local showers. An extensive heavy rain swept the valley between Farmington and Durango on August 21, and another widespread substantial rain occurred over September 12 and 13. The Animas River rose rapidly at this time, (see Figure 3) and collection of most environmental and river samples ended for the summer survey.

Rainfall during the summer of 1958 survey period totaled 2.93 and 3.90 inches at the two Durango gages and 3.15 and 2.24 inches at the two Farmington gages. If the heavier extensive rains of August 21 and of September 12-13 are deducted from these totals, there occurred at Durango 1.09 and 1.86 inches and at Farmington 0.88 and 1.10 inches of rain for the remainder of the survey period.

Although no definite data were obtainable regarding prevailing winds, the observer at Radio Station KIUP in Durango indicated his belief that, during the summer, winds at Durango were generally from the southeast and southwest.

SECTION III

THE FIELD SURVEY, 1958

River Sampling Stations

The location and description of the various sampling stations established for this survey are described below. The station numbers refer to the numbers shown on Figure 2. The basic survey of 1958 extended from July 18 through September 13. Following this, certain sample collections were continued by personnel of the local health agencies.

Station 1: Animas River above V.C.A. mill discharges. This station was selected on the basis of need for a sampling point sufficiently far above any discharges from the Vanadium Corporation of America mill to assure river samples uncontaminated by mill wastes. The location of the station was at the highway bridge on U. S. 550, 0.8 miles north on Main Avenue from junction with U. S. 160 in Durango, Colorado.

The station was about one river mile above any discharges from the Vanadium Corporation of America mill and about 100 yards below the Durango fish hatchery of the Colorado Department of Game and Fish. A U. S. Geological Survey stream gaging station is located about 100 yards downstream from the station.

The river at this point was relatively fast flowing, about 100-150 feet wide, and had an average depth of about five feet at the time of survey. The bottom was very rocky, with stones varying from about six inches to two feet in dimension.

The station was established on July 21, 1958, and sampled daily through September 13, 1958. The daily samples consisted of a one-quart grab sample composited from the quarter points across the stream. These daily samples were poured into a 5-gallon carboy in the laboratory and composited over a 7-day period. At the end of the 7-day period, the sample was shaken well, and a one-gallon sample was taken for the several analyses.

In addition to the water samples, bottom muds, algae, and bottom insects were collected every two weeks. At this particular station the bottom muds, algae, and insects were collected about 100 yards above the bridge in some riffles. On collection, algae were rinsed with river water to free them of silt, and insect larvae were removed from their cases. They were hand collected and composited across the river section.

Also during the daily sampling at this station readings were made of the river stage at the U.S.G.S. gaging station immediately below the sampling point in order to have a daily record of the flow of the river at this point.

Station 2: Animas River below V.C.A. mill discharges. This station was selected at a point where it was certain that the waste discharges from the V.C.A. mill had become thoroughly mixed with the river. The location of the station is as follows: proceeding south on 5th Avenue from U.S. 550 in Durango, Colorado, follow dirt road to first bridge; continue 1.1 miles to gate on left, follow farm road to small trout ponds, walk upstream to narrow island. The station was located about two river miles downstream from the V.C.A. mill.

The river at this point was relatively swift and was approximately 300 feet wide. The depth of the water varied from about three inches near the edge to about three feet near the center. The bottom was very rocky, the stones varying from pebble size to approximately two feet in dimension. During the entire sampling period there was prolific algal growth present, and the rocks were covered with thick slimy deposits of mud and growths of blue-green algae.

The station was established on the 19th of July, 1958, and was sampled daily through September 13, 1958. An automatic water sampler was installed at this station in order to obtain 24-hour composite samples. The sampler was a modified Trebler sampler(13) and was operated from a six-volt automobile storage battery. It consisted of an electric motor, gear reducer, microswitches, and a timer, with a scoop set to operate approximately every 15 minutes.

The sampler was installed on a stationary platform which could be raised or lowered as the level of the water dictated and was positioned so as to collect a minimum of two quarts of water during a 24-hour period. A one-quart sample was taken daily from this composite, and these quarts were composited over a 7-day period in the laboratory.

Biological samples, bottom muds, and algae were collected at this station every two weeks. They were hand collected and composited across the river section.

Station 3: Florida River above confluence with Animas River. The station was selected in order to provide data from another point where the water was uncontaminated by mill discharges and to provide data as to the quality and quantity of tributary flow. The location was as follows: 11.8 miles south of the south junction (near Carbon Junction) of U. S. 160-550 on U. S. 550, enter gate on left just before railroad crossing; take right fork to river's edge; sample at U.S.G.S. gaging station. The sampling point was approximately 300 yards upstream from the confluence with the Animas, and about 23 miles below the mill.

The Florida at this point had a slow velocity and was approximately 50-75 feet wide, with an average depth of about two feet. The bottom was rocky, the stones varying from pebble size to approximately six inches in diameter.

The station was established on July 21, 1958, and sampled daily through September 13, 1958. A one-quart grab sample was composited from the quarter points daily, and these were composited into a 7-day composite from which samples were taken for analysis. During collection of the daily samples the U.S.G.S. gaging station was read in order to have a continuous record of the daily flows.

Biological samples, bottom muds, and algae were also collected at this station every two weeks, and composited across the stream.

Station 4: Animas River above confluence of Florida River. The location of this station is as follows: proceed south 12.5 miles on U. S. 550 from the south junction of U. S. 160 and 550, and 0.7 miles south of railroad crossing. The river was sampled from the highway bridge. The river at this point was very swift due to its passing through a narrow rock formation, was approximately 150 feet wide, and had a depth of approximately 3-4 feet. This sampling station was about 23 miles below the Durango refinery.

The station was established on July 21, 1958, and was sampled daily through September 13, 1958. Daily grab samples composited from the quarter points were taken and composited in the laboratory into a 7-day composite from which the analyses were run.

Biological samples, bottom muds, and algae were collected in riffles at a point about 100 yards upstream from the sampling point. They were taken every two weeks, and composited across the river.

Station 5: Animas River at Colorado-New Mexico State Line. This station was selected so as to provide a continuous record of the condition of the river at the State line. The location of the station was as follows:

turn left into farmyard 3.7 miles south of highway bridge on U. S. 550 (Station 4); this farm entrance was also 0.1 mile north of the Colorado-New Mexico State line; follow farm road to fence and walk to river along trail leading across railroad tracks.

The station was established on July 19, 1958, and was sampled daily through September 13, 1958. An automatic water sampler, identical to the one installed at Station 2, was installed at this station. Samples were collected at this point in the same fashion and with the same frequencies as at Station 2.

The river at this point did not have such obvious turbulence as at previously described stations, but the current was still swift. It was approximately 250-300 feet wide and had an average depth of about three feet. The bottom was still very rocky with a preponderance of smooth stones about 6-8 inches in diameter. The bottom was very slick and had a definite algal growth during the period of sampling.

The sampling point at this location was approximately 28 river miles downstream from the waste discharges from the V.C.A. mill.

Station 6: Animas River at Farmington, New Mexico. The location of this station was as follows: the sampling point was at the highway bridge on New Mexico Route 17, approximately two miles east of Farmington, New Mexico. This station was about 59 river miles below the uranium ore refinery at Durango, and about three miles above the confluence of the Animas and San Juan Rivers.

The station was established on July 21, 1958, and sampled daily through September 13, 1958. A one-quart grab sample was composited daily from the quarter points and these were composited into a 7-day composite sample from which the analyses were run.

At this point the river flow is not too great due to the large volume of irrigation water taken off upstream. During the entire period of sampling at this point the river was divided into two sections separated by a small island. The river on one side of the island was very shallow, rocky, about 30-50 feet wide and had a swift current. The river on the other side of the small island was a small pool about 50 feet wide, the current was very slow, and the water averaged about 1-2 feet deep.

Composite biological samples, bottom muds, and algae were also collected at this station every two weeks.

Station 7: Water Treatment Plant - Aztec, New Mexico. Aztec's water supply is obtained from a ditch diversion from the Animas about three miles above the town. Raw and treated water were collected at this station. The plant operated 24 hours a day and the following sampling procedure was used: a one-pint sample of raw water was collected from the intake line each six hours; these pint samples were composited into a five-gallon carboy for a 7-day period. At the end of this 7-day period the composite was shaken well and a sample taken for analysis; the cycle was then started again. The same procedure was used for collecting and compositing treated tap water samples. The sampling was done by water plant personnel and started on July 18, 1958, and ended on September 18, 1958. Samples of filter sand were collected occasionally, both immediately before and after backwashing.

Station 8: Water Treatment Plant - Farmington, New Mexico. Raw and treated water were also collected at this station. Since this plant also had 24-hour operation, the same procedure was used for collection and compositing the raw and treated water samples and filter sands as was used at the Aztec water plant. (Station 7).

During the period of sampling, July 18, 1958 - September 18, 1958, the plant obtained part of its raw water from an irrigation ditch which had its intake from the Animas at Aztec, New Mexico, about 12 miles northeast of Farmington, and part of its raw water by direct pumping out of the Animas at Farmington.

Station 9: Water Treatment Plant - Shiprock, New Mexico. Only raw water was collected at this station. Since this station only operated 18 hours per day the following sampling schedule was set up: a one-pint sample was collected at the start of operations, at the change of shifts, and at the end of the day's operation. These samples were composited in the same fashion as at Stations 7 and 8.

The source of raw water for this plant was the San Juan River. During the period of sampling, July18, 1958 - September 18, 1958, about 50 per cent of the time raw water was taken from an irrigation ditch which obtained San Juan River water about 12 miles east of Shiprock, and about 50 per cent of the time raw water was pumped directly from the river after passing through infiltration galleries.

Station 10: Animas River immediately below V.C.A. main plant discharge. This station was established at a point approximately 100 yards downstream from the main plant discharge of the Vanadium Corporation of America mill. The river at this location contained all of the liquid effluents from the mill. Sampling was carried out from the mill side of the river, which was too deep and swift for wading. At this point the effluent had not completely mixed with the river, but trailed down the mill side of the river for a distance of approximately one-half mile before becoming completely mixed.

In order to obtain as representative as possible a sample reflecting the condition of the river at this point a daily grab sample was composited across the width of the river consisting of approximately two-thirds river water which looked clean to the eye and one-third from the portion of the river in which the mill effluent was flowing. While these samples may not be as truly representative as others, they are believed to yield useful results.

The station was established on July 31, 1958, and sampled daily through September 13, 1958.

The river at this point was approximately 150-200 feet wide, had a swift current, and an average depth of three feet or more. The bottom was very rocky with the rock varying from 2-3 inches in diameter up to boulders three feet in diameter. The rocks on the mill side of the river were coated with a thin slimy layer of yellow material, and the bottom had considerable deposits of sand.

Station 11: Lightner Creek above confluence with Animas River, below final tails discharge of V.C.A. mill. The location of this station was at the bridge leading into the uranium mill. The point of sampling was approximately 200 feet below the final tails discharge of the mill. The creek at this point was approximately 15-20 feet wide and had an average depth of about six inches. The bottom was rocky, and these stones were coated with slimes from the mill discharge.

The station was established on July 31, 1958, and sampled daily whenever there was a final tails discharge into the creek. The samples were composited into a 7-day composite from which samples were taken for analysis. No biological life was evident, and no biological samples were obtained.

Station 12: Lightner Creek above final tails discharge from V.C.A. mill. The location of this station was approximately one-quarter mile above Station 11 and was above the final tails discharge from the mill. The station was established on July 31, 1958, and sampled daily whenever there was a final tails discharge from the mill.

The creek at this point was about 30 feet wide and averaged about 6-8 inches in depth. The bottom was rocky and the rocks had a natural coloration associated with them. Aquatic biota were available here and were sampled several times.

Station 13: Final tailings pond discharge. This effluent from the Vanadium Corporation of America uranium refinery was sampled as it flowed either to Lightner Creek or to the Animas. The station was established on August 6, and sampled daily through September 5, 1958. One-quart instantaneous daily samples were taken and composited in the laboratory for a 7-day period. Notes were kept as to whether daily flow was to the Animas or to Lightner Creek.

Station 14: Main plant discharge to Animas. This effluent ditch was sampled at a point near the company office and laboratory building. The station was established on August 6, and sampled daily until September 13, 1958. One-quart daily grab samples were composited in the laboratory for 7-day periods.

U. S. Geological Survey Gaging Stations

In addition to the above river sampling stations the following U. S. Geological Survey gaging stations were read daily during the entire period of sampling:

1. Animas River at Durango, Colorado.
2. Florida River near confluence with Animas.
3. Animas River near Cedar Hill, New Mexico (about one mile below confluence of Florida River).
4. Animas River at Aztec, New Mexico (wire-weight gage installed by U.S.G.S. during survey).
5. Animas River at Farmington, New Mexico.
6. San Juan River at Shiprock, New Mexico (lower gage).

Dissolved Oxygen, Biochemical Oxygen Demand and Bacteriological Sampling Stations

Five stations were established on the Animas from above Durango to Farmington for collections of samples for dissolved oxygen (D.O.), biochemical oxygen demand (B.O.D.) and coliform bacteria (M.P.N.) analyses. Dissolved oxygen samples were collected at each station on August 13 and 26 and on September 10, 1958. They were duplicate samples, fixed in the field and titrated later in the laboratory. Coliform bacteria samples were collected on the same dates in sterile bottles and transported to the field laboratory for analysis. B.O.D. samples were collected at each station on August 12 and 25 and September 9, 1958, and transported immediately to the field laboratory for analysis.

The sampling stations were as follows:

Station Q-1: about 5 miles upstream from Station 1 of the routine river water stations. Station Q-1 was established at this location in order to be above any significant pollution from the Durango area.

Station Q-2: corresponded to Station 2 of the routine river survey, and was located well below the sources of pollution for the Durango area.

Station Q-3: corresponded to Station 5 of the routine river survey, at the Colorado-New Mexico State boundary.

Station Q-4: This station was about 49 river miles below the Durango uranium refinery and about 10 miles upstream from Station 6 of the routine river survey; it was reached by proceeding west on U.S. 550 4.8 miles from the bridge over the Animas at Aztec, and following a dirt road on the left 1.4 miles to the river. This station therefore included any wastes discharged at Aztec, New Mexico.

Station Q-5: established on the San Juan River about 100 yards below the discharge from the Farmington Municipal Sewage Treatment Plant.

Fish Samples

Representative fish samples were collected on August 20, 1958, by personnel of the Colorado Game and Fish Department at three river locations, as follows: upstream, at Station Q-1 of the organic pollution survey, about one mile below the uranium mill at the wooden bridge over the Animas (one mile upstream of Station 2 of the routine river survey), and in the vicinity of Station 5 of the routine river survey, near the State boundary.

Vegetable Samples and Irrigation Water Samples

In addition to the river water samples collected, a number of farms were visited periodically during the survey in order to obtain vegetable samples, farm topsoil, and irrigation water.

Three of the farms visited were located generally north of Durango and upstream from the uranium mill. Representative vegetable and crop samples were also obtained from a total of six farms located downriver from the mill, in both Colorado and New Mexico. All of the farms involved used Animas River water for irrigation during the growing season. The various owners were most cooperative in making crop samples available.

Certain of the farms, one in New Mexico and one north of Durango, grew a wide variety of crops and were able therefore to provide a good variety of samples. Others were more limited in that sense.

The variety of crops involved is indicated along with the analytical results in Section VI. In addition to those crops consumed directly by humans, alfalfa samples were taken at several farms because it is an important crop of the area.

Precipitation

Rain sample collectors were located on the roofs of the San Juan County Health Department Laboratory Building in Farmington, and the San Juan Basin Health Unit Building in Durango. The samplers were constructed of galvanized metal, and were designed as shown in Figure 12. Samples of each rain of appreciable magnitude were thus collected at the two locations.

Milk Samples

Beginning in August, milk samples were obtained for radiochemical analyses. These samples consisted primarily of single monthly collections of raw milk as delivered to a transfer station in Farmington, New Mexico. Each consisted of a representative portion of the bulk delivery from one of three milk sheds. Two of the raw milk collection routes were located in southwestern Colorado, one in Montezuma County, west of Durango, the other in La Plata County, generally south and east of Durango. The third route was located in the plateau region extending west from Farmington to Shiprock, New Mexico.

A separate liter sample was obtained at the time of the first collection and forwarded to Salt Lake City for radium analysis.

As these monthly samples represented only raw milk as collected in the area, a special monthly composite of pasteurized milk was obtained from November 10 to December 10, 1958. For this sample, one-half pint portions of milk as delivered to the local consumer were composited every other day for the one month period.

Personnel and Equipment

A basic field crew of five technical personnel was available for the duration of the field survey. Of these, three were sanitary engineers, one was a radiochemist and one a laboratory aide. In addition, at various times during the survey two sanitary engineers, an aquatic biologist and a laboratory aide performed special assignments. These included responsibility for the surveys of the aquatic biota, the bioassay studies, the in-plant survey of the Vanadium Corporation of America refinery, and assistance to the basic field team as required. An additional chemist for radium work was assigned at the Salt Lake City, Utah, Public Health Service Field Station.

The daily field sampling was carried out by a team of two. All members of the basic field group were familiar with the sample run and collection methods, and the daily two-man field team had varied members. One engineer worked in the field laboratory at all times, resulting in a regular laboratory team of the chemist, an aide and an engineer. Both field and laboratory records were systematized in a fashion such that all personnel could adequately perform tasks such as recording data in the field and laboratory notebooks.

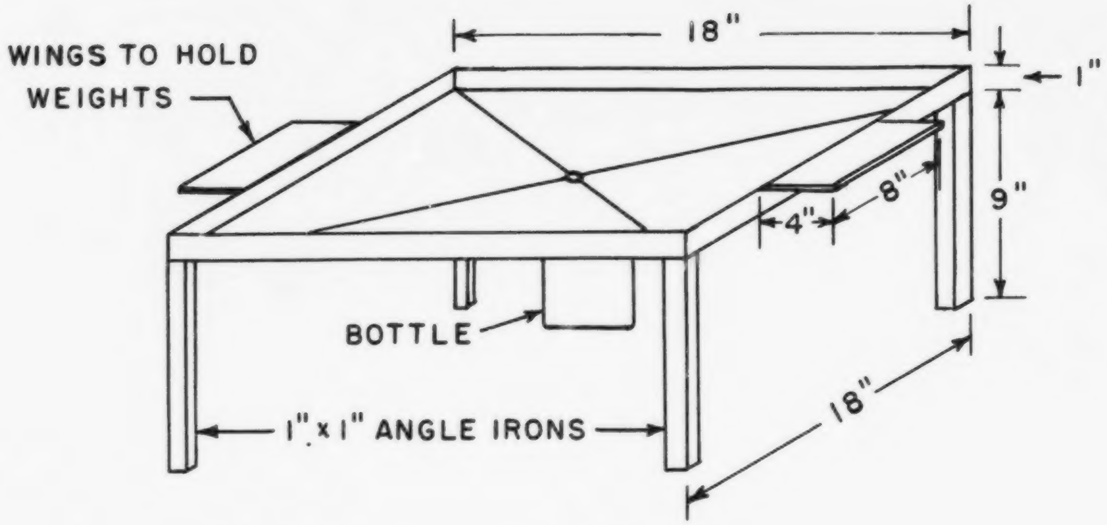
In addition to the foregoing available personnel, assistance was provided by both the State and local health agencies in special assignments of gathering information, collection of certain samples, and some field participation. Following the field survey, several chemists and engineers of the Robert A. Taft Sanitary Engineering Center aided in special analyses of samples.

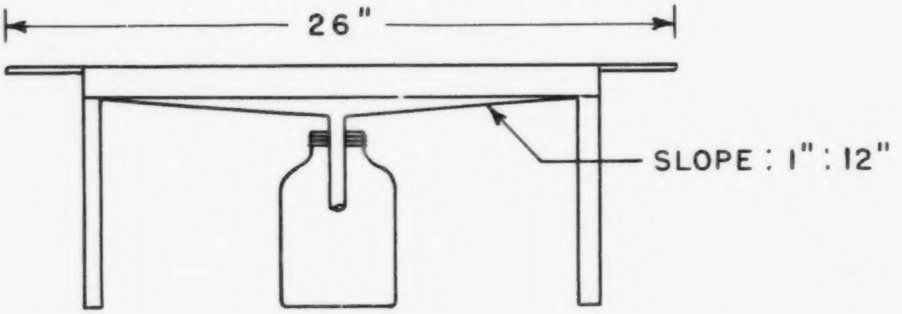
Two station wagons were available at all times during the field operations.

Field sampling equipment included the two automatic samplers, rain samplers, square yard samplers for bottom fauna, dredges, and sundry sample containers such as polyethylene bottles, jars, glass bottles, vials, etc., in a variety of sizes.

A large laboratory area was made available at the Farmington Laboratory of the San Juan County Health Department. The basic area consisted of three separate rooms with additional storage area. This space was fully served by water, waste disposal, gas, electricity, etc. In addition to the main laboratory, one small room was used strictly for a counting room, and the third room was reserved for the handling of higher level samples such as mill effluents. Certain other facilities such as constant temperature boxes were made available in other parts of the building.

Equipment for this field laboratory was brought from the Robert A. Taft Sanitary Engineering Center. Two gas flow internal proportional counters, an analytical balance, drying ovens, muffle furnace, soil grinding equipment, miscellaneous glassware, membrane filter equipment, vacuum pumpt, and other such material were shipped or transported by station wagon, installed, and used for the duration of the survey. Chemical reagents and other such items were purchased locally.


WINGS TO HOLD WEIGHTS
18"
1"
9"
8"
4"
BOTTLE
18"
1" x 1" ANGLE IRONS


26"
SLOPE : 1" : 12"

PRECIPITATION SAMPLER

FIGURE 12

SECTION IV

LABORATORY PROCEDURES

Quite a large number of samples of many types were processed and handled at the Farmington field laboratory during the survey. In general, all samples were processed to necessary stages for subsequent analysis at Cincinnati or Salt Lake City, with certain samples being fully analyzed at Farmington. The local processing and analysis was generally dictated by the type of sample, and was as noted in subsequent paragraphs of this section. Samples prepared for radium analysis were shipped promptly to the chemist at the Salt Lake City Field Station, and all other samples processed for subsequent analysis were shipped to the Robert A. Taft Sanitary Engineering Center at Cincinnati, Ohio.

Sample Processing

In view of the large number of samples involved, every effort was made to hold to a minimum the necessary laboratory work at the Farmington laboratory. Because of the expected presence of short-lived radioisotopes, rain samples, for example, were assayed for gross radioactivity immediately after collection. On the other hand, radium-226 is long-lived, hence portions for radium analysis did not require speed of handling and analysis, but only preliminary processing.

All samples were assigned a code number and entered in the log book upon receipt at the field laboratory. Following this, they were processed in turn, each processing and handling procedure being entered in the laboratory record books as completed. In this manner it was possible to know at any time the exact stage of processing or analysis of any individual sample.

The following sample handling and processing, and analysis operations were performed:

Water Samples. Upon completion of the compositing process, water samples were filtered through membrane filters, and separate portions of the filtrate were taken for gross assay, radium analysis, chemical analysis, and/or possible strontium analysis. In most cases the gross assay was performed at once, and the sealed portions were shipped to the respective centers for other analyses.

The filtered solids from the water samples were dried and weighed. These samples were then either assayed for gross radioactivity by methods outlined later, or were placed in vials which were sealed and stored for later analysis.

Irrigation ditch water samples were handled similarly, as were rain samples, except that the latter were all assayed for gross radioactivity because of the presence of short-lived radioisotopes. Rain samples were counted immediately on preparation, one week, and one month later, in order to know how each decayed.

Muds, Topsoils, Filter Sands. These samples were dried, and then, using a sample splitter, representative portions were taken, dried, ground to less than 100-mesh, weighed, and placed in vials which were then sealed. Gross radioassay was performed at once on selected samples. Other portions were shipped for radium, strontium, possible chemical, and remaining gross radioactivity analyses.

Mill Samples. Samples from the intensive mill survey and routine mill effluent samples often contained large quantities of suspended solids in the form of sands and slimes. Occasionally the membrane filters became clogged very quickly. In these cases, Whatman #40 filter papers were substituted for the membrane filters. With this exception, mill samples were handled in similar fashion to the water samples. The samples having high suspended solids content yielded relatively large quantities of filtered solids. These were then treated in fashion similar to muds and topsoils, being handled in a separate room, ground to less than 100-mesh, dried, weighed, and sealed in vials for shipment. Gross radioassay was performed at Farmington on selected mill samples. Portions were preserved for gross radioassay, radium, and chemical analyses.

Algae. The algae collected at the various river stations every two weeks were first washed in the laboratory in distilled water to free them insofar as possible from attached silt. An attempt was made to blot them gently and obtain a wet weight. Following this, they were dried, weighed, and either ashed and assayed at once for gross activity, or sealed in vials in the dry state for shipment. Portions were taken for the radium, gross radioassay, and strontium analyses.

Bottom Insects. These samples, collected at the same places and times as the algae samples, were processed in much the same manner. Washing them free of silt was in some ways more difficult because of the larval casings.

Fish. Fish samples consisted of both large adult fish and minnows. They were separated and packaged as to kind (trout, sucker, dace, etc.) upon collection, and received in the laboratory in the original state. There they were frozen pending processing. For minnows, processing consisted of obtaining the wet weights of a representative number, and their lengths, homogenizing the group in a Waring blendor, drying, and weighing. Representative portions were then taken, weighed, and sealed in separate vials for gross radioassay, radium analysis, and strontium analysis.

Large fish were dissected so as to obtain separate samples of bone and of edible flesh. Except for the head, most of the skeleton was taken for the bone samples. The flesh was dried and weighed and portions taken for gross assay, radium, and strontium analysis. Bone samples were dried and weighed and portioned for the same analyses.

Vegetables. As indicated in later sections, a wide variety of vegetable samples was collected from a number of farms. The samples included root vegetables, leaf vegetables, fruits, cereals, and grains. In general, all samples of vegetables commonly consumed by humans were washed and cleaned in a manner calculated to approximate that commonly used in households. The cleaning procedure was especially important in an attempt to rid root and low-growing leaf vegetables from soil particles. Oats and wheat were hand-husked, but were not washed. In the first vegetable collection relatively small quantities were obtained, some, such as carrots, in early development stages. Later collections were of larger quantities.

The individual vegetable samples were packaged in the field in paper bags and delivered in the live state to the laboratory. There they were washed, weighed, dried, and weighed, and representative portions taken for gross assay, and radium analysis. Representative portions for strontium analysis were washed and weighed, cut up in some cases such as fruits, string beans, etc., and placed in large glass jars, preserved with formaldehyde, sealed, and stored for shipment.

Milk. Milk samples were simply placed in containers, formaldehyde was added as a preservative, and they were sealed and shipped for strontium and radium analysis.

Analytical Methods

The analytical techniques here described are as used either at the Farmington field station, the Salt Lake City, or the Cincinnati laboratories.

Gross Radioactivity. Water filtrates were evaporated in quantity sufficient to provide at least 400 mg. of dissolved solids. These solids were ground to a powder and planchets prepared for counting. Procedures for preparing planchets and interpretation of results were as outlined elsewhere.(14)(15) Membrane filters were burned off at 600°C in closed crucibles, the solids were ground and planchets prepared and counted as for the filtered solids.

Algae, insects, fish, and vegetation were dry ashed at 600°C, and planchets then prepared and counted as usual. Topsoils, silts and filter sands were dried at 105°C to constant weight, planchets were prepared and counted as noted.(14)(15)

Mill filtrates were prepared and counted as were the water samples; mill solids were prepared and counted in similar fashion to mud and topsoil samples.

Precipitation samples were treated like usual water samples, except that, as noted before, several successive counts were made in order to observe the rate of decay of activity.

Radium. Radium was generally determined by coprecipitation with barium sulfate, removal of polonium and purification of the residue. A growth period of 30 days was then allowed so as to achieve full equilibrium of radium with its immediate daughters. The prepared planchet was then assayed for alpha activity in internal proportional counters. A radon emanation technique, employing a modification of Shandley's equipment,(16) was used for vegetables and certain other samples. This technique was particularly helpful for the determination of radium in certain mill samples having a high ratio of uranium to radium. All solids samples were put into solution by various accepted methods prior to the radium determination.

Strontium.(17) For water samples, strontium carrier was added to the filtrate and $SrCO_3$ precipitated by addition of 6M NaOH and 3N Na_2CO_3. Following digestion of the carbonate precipitate, it was dissolved in water containing 6M HCl. Rare earths were removed by the use of a mixed rare earth carrier followed by scavenging with NH_4OH. Carbonates were reprecipitated with Na_2CO_3 and a two-week period was allowed for ingrowth of yttrium-90. The carbonates were then redissolved and fuming HNO_3 added to precipitate strontium nitrates. Extraction with 14M HNO_3-equilibrated

TBP followed, and the TBP was back-extracted three times with three portions of 0.1M HNO_3. The aqueous portions were collected, dried, and counted.

For silt and soil samples, strontium-barium carrier was added and the samples ashed at 600°C for several hours. A carbonate fusion was performed on the ash, the fusion placed in hot water, and boiled to disintegrate the fusion melt. After the melt completely disintegrated, the samples were centrifuged and the supernatant discarded. The precipitate was dissolved in 6N HCl and the solution treated as a water sample.

Samples of the aquatic biota were dried at 105°C and ashed with mixed strontium-barium carrier. The ash was dissolved with alternating HCl and HNO_3 techniques. Excess Na_2CO_3 was then added and the resulting precipitate dissolved and treated as a water sample.

Samples of vegetation were each homogenized in a blendor after adding strontium-barium carrier, and then treated in the same fashion as samples of the aquatic biota.

Gamma Scan. Thirteen of the samples were scanned on a multichannel pulse height analyzer for significant activity peaks within the energy range 0 to 2 Mev. In one instance five silt and soil samples were examined as a group. Hundred-minute scans were performed using a two-inch flat NaI-Tl crystal and the significant gamma photopeaks recorded.

Chemical Analyses. Determinations were made on eight day composites from the two mill effluents, Stations 13 and 14. These samples were filtered through Whatman #40 filter paper and analyzed for cations and anions by standard methods.(18) Beryllium was determined by an unpublished aluminum -EDTA method used at the Robert A. Taft Sanitary Engineering Center. Selenium was determined by the 2-2' Diaminobenzedrine method.(19) Sulfates were determined by the turbidimetric method.(18)

In addition to the metal and non-metal analyses the samples were examined for extractable organics. The samples were extracted with ethyl ether and analyzed by infrared spectroscopy. The techniques used were designed to recover organics such as solvents or hydrocarbons. Sewage, or other B.O.D.-producing materials, would not be measured. The extraction procedure was applied to the entire sample including the suspended solids. It is not known whether the recovered organics were in solution or possibly adsorbed in the silt. The butyl phosphate could easily be in solution since the compound's solubility is well within the concentration found.

Weekly composites for all regular river sampling stations were analyzed for metals and non-metals in the same manner as the mill effluents.

B.O.D., D.O., and bacteriological analyses were performed by the procedures outlined in Standard Methods for the Examination of Water, Sewage, and Industrial Wastes.(18) The azide modification of the Winkler method was used for D.O. analysis.

SECTION V

THE MILL PROCESS AND SURVEY

With the cooperation of officials and personnel of the Vanadium Corporation of America, an in-plant survey of that company's uranium ore refinery at Durango was performed during the period July 28 through August 5, 1958. The refinery extracts both vanadium and uranium from the ores received. Only a week prior to this survey the process for recovery of uranium from acid leach liquor was substantially modified by changing from an acid purification process to the solvent extraction method. At the time of the survey the mill was handling slightly more than 500 tons per day of ore, and had plans to increase capacity toward 700 or 750 tons per day.

The Mill Process

Figure 13 is a detailed diagram of the process in operation at the mill during the 1958 survey. The vanadium and uranium circuits, together with the location of sampling points and other pertinent information are shown. Referring to this flow sheet, the full process may be described as follows:

Ore Receiving, Sampling, and Crushing. Loaded ore trucks are driven onto a scale in the receiving area, weighed, and assigned a lot number. The load is then dumped either into the sampling plant or onto the stockpile, dependent on the available space. Ore from company owned mines is sampled prior to delivery to the mill, and is put directly onto the stockpile.

As the first step in processing, all ore is crushed to 1-1/2 inch size in jaw crushers, following which it is moved either back to the stockpile or to the crushed ore storage bins. There are three of these bins having a total capacity of 490 tons. Crushed ore goes from the storage bins or stockpile to a rotary gas fired dryer where the moisture content is reduced to about 3 per cent by weight. The dried ore then passes over a 14 mesh screen where fines drop into the fine ore bins, of which there are two with a total capacity of 400 tons. Material larger than 14 mesh goes to one of three rod mills, where it is ground and re-fed to the screen over the fine ore bins.

Roasting. The material from the fine ore bins is carried by a belt conveyor across an automatic weigher, and dropped into an elevator which carries it into the roasters. As the ore drops from the conveyor a sample for assay is taken by an automatic sampler (about 0.7 pounds per ton). Sodium chloride is added in an amount equal to 100 pounds per ton of ore, and the ore salt mixture proceeds to the roasters.

Roasting is carried out in six multiple hearth roasters. This process takes from 45 minutes to one hour. Temperature of the bottom hearth is 1550 degrees Fahrenheit. The purpose of the roasting is to convert insoluble vanadium compounds in the ore to soluble sodium vanadates. While specific chemical reactions for this process cannot be written due to the complexity of the vanadium compounds involved, the general course of the process may be indicated as follows:

$$\begin{array}{l}\text{Complex Vanadium Compounds}\\ (\text{Insoluble in } H_2O \text{ or } Na_2CO_3)\end{array} + NaCl + O_2 \xrightarrow{\text{Heat}} \begin{array}{l}\text{Sodium Vanadates}\\ (\text{Soluble in } H_2O)\\ (\text{ or } Na_2CO_3\ )\end{array} + \begin{array}{l}\text{Other}\\ \text{Compounds}\end{array}$$

Plant personnel have indicated that (a) without roasting recovery of vanadium from the ore would be in the order of 15-20%, while with roasting recovery is increased to 75-80%, and (b) the solubility of uranium compounds in the ore is slightly decreased by roasting (these compounds being soluble in an Na_2CO_3 solution, but not in H_2O).

Each roaster is equipped with a quench tank into which the calcined ore, together with a 5% Na_2CO_3 solution, is discharged. The Na_2CO_3 solution comes from the alkaline leach circuit tank, and contains some uranium and vanadium which have been recovered from the ore during both the alkaline leach and solvent extraction processes. (See discussion below and Figure 13).

Alkaline Leach. Slurry from the quench tanks goes to one of ten alkaline leach tanks (8 tanks - 90 tons each, 2 tanks - 210 tons each). The slurry is run into a tank until it is filled with sand. Then about 1,000 pounds of Na_2CO_3 are run on top of the sand as a 40% solution and

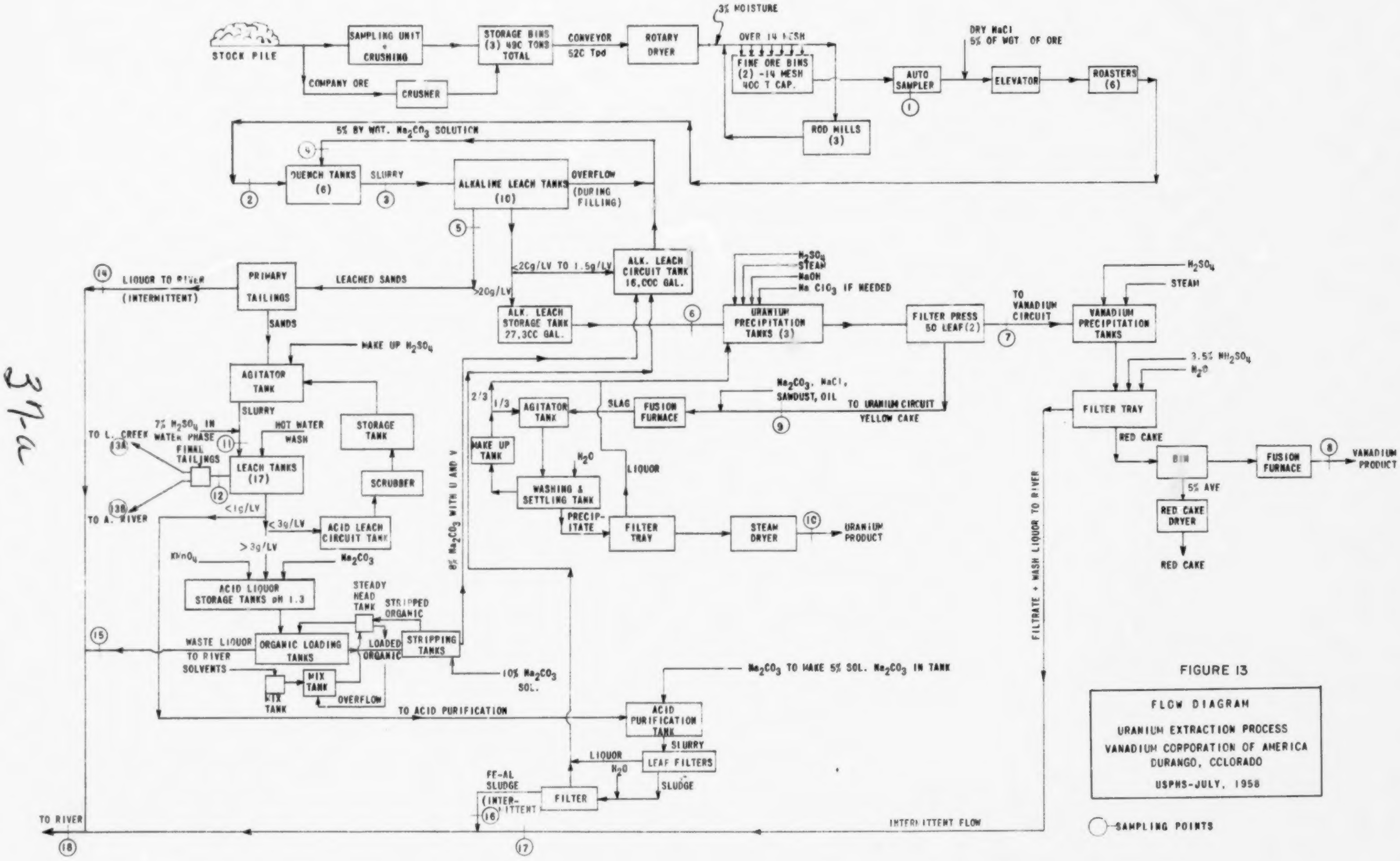

STOCK PILE
SAMPLING UNIT + CRUSHING
COMPANY ORE
CRUSHER
STORAGE BINS (3) 49C TONS TOTAL
CONVEYOR 52C Tpd
ROTARY DRYER
3% MOISTURE
OVER 14 MESH
FINE ORE BINS (2) -14 MESH 40C T CAP.
ROD MILLS (3)
AUTO SAMPLER
①
DRY NaCl 5% OF WGT. OF ORE
ELEVATOR
ROASTERS (6)
5% BY WGT. Na_2CO_3 SOLUTION
④
QUENCH TANKS (6)
②
SLURRY
③
ALKALINE LEACH TANKS (10)
OVERFLOW
(DURING FILLING)
⑤
<2Cg/LV TO 1.5g/LV
>20g/LV
ALK. LEACH CIRCUIT TANK 16,COC GAL.
ALK. LEACH STORAGE TANK 27,3CC GAL.
⑭
LIQUOR TO RIVER (INTERMITTENT)
PRIMARY TAILINGS
LEACHED SANDS
SANDS
MAKE UP H_2SO_4
AGITATOR TANK
SLURRY
7% H_2SO_4 IN WATER PHASE
HOT WATER WASH
⑪
TO L. CREEK
13A
FINAL TAILINGS
13B
TO A. RIVER
LEACH TANKS (17)
⑫
STORAGE TANK
SCRUBBER
<1g/LV
<3g/LV
ACID LEACH CIRCUIT TANK
>3g/LV
$KMnO_4$
Na_2CO_3
ACID LIQUOR STORAGE TANKS pH 1.3
STEADY HEAD TANK
STRIPPED ORGANIC
⑮
WASTE LIQUOR TO RIVER
ORGANIC LOADING TANKS
LOADED ORGANIC
STRIPPING TANKS
SOLVENTS
MIX TANK
MIX TANK
OVERFLOW
10% Na_2CO_3 SOL.
8% Na_2CO_3 WITH U AND V
TO ACID PURIFICATION
⑥
H_2SO_4
STEAM
NaOH
Na ClO_3 IF NEEDED
URANIUM PRECIPITATION TANKS (3)
FILTER PRESS 5C LEAF (2)
TO VANADIUM CIRCUIT
⑦
2/3
1/3
AGITATOR TANK
SLAG
FUSION FURNACE
Na_2CO_3, NaCl, SAWDUST, OIL
⑨
TO URANIUM CIRCUIT
YELLOW CAKE
MAKE UP TANK
H_2O
WASHING & SETTLING TANK
LIQUOR
PRECIPITATE
FILTER TRAY
STEAM DRYER
⑩
URANIUM PRODUCT
H_2SO_4
STEAM
VANADIUM PRECIPITATION TANKS
3.5% NH_2SO_4
H_2O
FILTER TRAY
RED CAKE
BIN
5% AVE
RED CAKE DRYER
RED CAKE
FUSION FURNACE
⑧
VANADIUM PRODUCT
FILTRATE + WASH LIQUOR TO RIVER
Na_2CO_3 TO MAKE 5% SOL. Na_2CO_3 IN TANK
ACID PURIFICATION TANK
SLURRY
LIQUOR
LEAF FILTERS
H_2O
SLUDGE
FE-AL SLUDGE (INTERMITTENT)
⑯
FILTER
INTERMITTENT FLOW
TO RIVER
⑱
⑰
SAMPLING POINTS

FIGURE 13

FLOW DIAGRAM

URANIUM EXTRACTION PROCESS
VANADIUM CORPORATION OF AMERICA
DURANGO, COLORADO

USPHS-JULY, 1958

flushed through it with a continuous water wash. It takes about 12 hours to fill each of the 90-ton tanks, and 24 hours to fill each of the 210-ton tanks. Leaching time is about 20 hours, following which the leached sand is sluiced out of the tank with water and pumped to a primary tailings pond to be further processed by the acid leach-solvent extraction process.

Each leach tank is equipped with a false bottom for withdrawal of the leach liquor. During the filling operation the liquor drawn from the tank bottom is run into a storage tank of 27,000 gallons capacity. Following addition of the Na_2CO_3 solution, and during the subsequent water wash, the liquor continues to be fed to the storage tank until the vanadium concentration falls below 20 gm/l. At this time the liquor is then fed to the alkaline leach circuit tank until the vanadium concentration is less than 1.5 gm/l. The water wash is then stopped, the remaining liquor is drained into the circuit tank and the sands sluiced from the leach tank as described above.

During the leaching process, the soluble sodium vanadates, together with uranium compounds which are soluble in Na_2CO_3 solution, are recovered from the ore.

Uranium Precipitation. Liquor from the alkaline leach storage tank goes to one of three uranium precipitation tanks, having a capacity of 9,280 gallons each, for precipitation of uranium as U_3O_8. On filling a tank, the contents are heated with steam to 190 degrees Fahrenheit and concentrated H_2SO_4 is added to pH 5.8 when the following reaction occurs:

$$\underset{\text{(Soluble)}}{\underset{\text{Uranium}}{Na_2CO_3\text{ Salts of}}} + 4H_2SO_4 \xrightarrow{\text{pH 5.8}} \underset{\text{(Insoluble)}}{2UO_2SO_4} + \underset{\text{(Insoluble)}}{U(SO_4)_2} + 4H_2O + \underset{\text{Products}}{\text{Other}}$$

At this point some sodium chlorate may have to be added to oxidize reduced substances entering the precipitation tank from the uranium filter tray overflow. Tank contents are agitated for from 45 minutes to one hour. Dry NaOH is then added to raise the pH to 7.2. Agitation continues for one to two hours additional, and the tank contents are then filtered through one of two 50-leaf filter presses, where uranium is removed as yellowcake. The filtrate proceeds to the vanadium circuit for further processing for removal of vanadium.

Action in the precipitation tank may be summarized as follows. Addition of the acid destroys the sodium carbonate solution and transforms the uranium to an insoluble form. Some carbon dioxide remains in solution, and will keep some uranium in the dissolved state, unless it is driven off by heating the solution to the temperature indicated. The pH of the solution is raised from 5.8 to 7.2, since complete precipitation of the uranium occurs at about pH 7. The addition of sodium hydroxide insures that this will occur.

Yellowcake Processing. Yellowcake coming off the filter press contains about 20% vanadium, and is high in impurities (sulfates and chlorides) some of which are insoluble. The yellowcake is mixed with a flux of sawdust, diesel oil, sodium carbonate, and NaCl, and fired in a fusion furnace for about two hours. The purposes of this process step are to (1) reduce the uranium compounds to a state in which they are insoluble in water and reduce the vanadium compounds to a state in which they are soluble in water, and (2) form salts of chlorides and sulfates which are soluble in water.

At the end of the firing time the furnace is tapped and the slag broken into pieces which are then placed in an agitator tank (5-feet diameter by 5-feet depth) and agitated for 16 hours with a solution consisting of 1/3 of the wash liquor from the previous agitation process and sufficient fresh water to make up a volume to cover it. During the agitation the vanadium and all other soluble salts are dissolved in the liquor, while the uranium remains as an insoluble precipitate. The agitation tank contents are then pumped to a wash tank (8-feet diameter by 10-feet depth), the liquor returned to the uranium precipitation tanks, and the precipitate given two washings with water in an amount equal to about 1/2 the tank volume. Two-thirds of the wash liquor is returned to the uranium precipitation tanks, and the remaining 1/3 stored for use in the next agitation process.

The washed uranium precipitate is dumped into a filter tray and vacuum dried, the filtrate also being returned to the uranium precipitation tanks. The cake is transferred to a steam table where it is dried by steam heat, screened to a maximum size of 1/4 inch, barreled, and shipped to the Atomic Energy Commission.

Vanadium Production. Filtrate from the yellowcake filter presses goes to one of four vanadium precipitation tanks. Constant agitation of the tank contents is provided by an agitator mechanism in each tank. When a tank is filled with the vanadium liquor the temperature is raised to 190 degrees Fahrenheit with steam and H_2SO_4 is added continuously until the clear liquor tests in excess of 1 gm/l. acid and vanadium is less than 0.25 gm/l. The tank contents are then discharged to a filter tray, and the liquor is drained off by application of a vacuum, and discharged to waste. The reactions occurring during this process may be characterized as follows:

$$Na_3VO_4 + H_2SO_4 \xrightarrow{\text{Heat}} Na_2SO_4\downarrow + V_2O_5\downarrow + H_2O$$

The redcake remaining on the filter tray is washed with a 3-1/2% NH_2SO_4 solution (about 50 pounds of NH_2SO_4 per tray being used). The NH_2SO_4 wash converts the insoluble Na_2SO_4 to soluble NH_4SO_4. The primary purpose of this wash is to reduce the sulfur content of the product. Three water washes follow, totaling approximately the volume of the liquor drained from the tank. All wash liquors go to waste.

The washed redcake is stored in a 12-feet by 8-feet by 15-feet bin. About 95% of the product is loaded into a fusing furnace and fired to a temperature of 1,800 degrees Fahrenheit which is held until the furnace goes dry. There is no chemical reaction in the furnace. The redcake merely melts and fuses while water, NH_2SO_4, and all other extraneous material is burned off. The molten product runs out of the furnace in a small trickle onto a small revolving platform, from which it is automatically scraped off, and falls into a collecting tray. After cooling, the product is loaded into drums. Fusion time will run from six to eight hours per charge.

About 5% of the redcake coming off the filter trays is dried in a rotary gas fired dryer, and shipped in barrels or bags to the consumer.

The main process flow has been described above. As was mentioned, sands leaving the alkaline leach tanks are further processed by the acid leach-solvent extraction method for the removal of additional uranium and vanadium. This process is considered below.

Acid Leach. Sands from the alkaline leach tanks are run into an intermediate tailings pond from which they are bulldozed and flushed as a 60% slurry into an agitator trough where concentrated H_2SO_4, is added to make a 7% solution by weight of water (not weight of slurry). As the slurry leaves the trough, Separan is added to floc the slimes, and the slurry is discharged to one of seventeen acid leach tanks (average capacity each tank 60 tons sand). As the tank fills, the liquor coming off the bottom goes to one of three storage tanks (capacity 27,000 gallons each). When a tank is full, hot water is run onto the tank contents as a continuous wash during the leaching period. The bottom liquor continues to be fed to the storage tanks until the vanadium concentration is less than 3 gm/l., at which time the feed is diverted to a weak liquor tank (12-feet diameter by 12-feet depth) until the vanadium content is less than 1 gm/l., when the wash is discontinued, and all liquor drained from the tank. Contents of the weak liquor tank are used to scrub stack gases, run into a storage tank (16-feet diameter by 16-feet depth) and used as make-up liquor for the agitator tank. The spent sands are flushed from the tank with water and pumped to the final tailings pond.

Solvent Extraction (SX). Shortly prior to the beginning of the survey, a major process change was introduced by the addition of a solvent extraction plant for recovery of uranium from the acid liquor. This plant had been in operation about one week at the time of the survey, and about 80-90% of the acid liquor was being processed by this method during the survey. The remaining 10-20% of acid liquor was being processed in the original "acid purification" section, which is described later.

As mentioned above, pregnant acid liquor from the leach tanks goes to three storage tanks preceding the solvent plant. When a storage tank is filled the pH of the contents is adjusted to about 1.3 by the addition of Na_2CO_3 as a 40% solution. $KMnO_4$ solution is added to oxidize vanadium which is present. A full storage tank is held for about 8 hours before entering the solvent plant. This was due to the physical capacity of the plant.

Solvent extraction is carried out in four tanks (each 12-feet diameter by 12-feet deep) arranged in series. Flow is counter-current, the pregnant acid liquor proceeding from tank number 1 to tank number 4, while the organic flows from tank number 4 to tank number 1. Each tank contains a mixing chamber into which the acid liquor and solvent are fed intermittently and mixed with a propeller mixer, following which the mixture is allowed to form an interface in a settling chamber. Acid liquor is withdrawn and enters the next tank, while the same is true of the solvent. From tank number 4 the barren acid liquor is discharged to waste. About 8 hours are required for the acid liquor to progress from entrance in tank number 1 to discharge in tank number 4. In tank number 2 solvent from tank number 3 is enriched with additions of fresh solvent as required.

The loaded solvent then goes to the first of two stripping tanks arranged in series, in which the uranium and vanadium is stripped from the solvent by a 10% Na_2CO_3 solution. The flow in these tanks is also counter-current, and the process is the same as in the extraction tanks. Stripped organic is returned to the solvent extraction tanks, while the loaded Na_2CO_3 solution is discharged to the alkaline leach circuit tank, and proceeds via the quench tanks and alkaline leach tanks to the uranium and vanadium precipitation circuits. About 6 hours are required for the stripping operation.

Acid Purification. As stated above, about 10-20% of the liquor leaving the acid leach tanks was being treated by this process whose purpose is to remove impurities which would interfere with subsequent processing of the liquor. In this operation the acid liquor is run into an acid purification tank, and a 40% Na_2CO_3 solution is added until the tank contents consist of a 5% Na_2CO_3 solution. When the pH reaches 7, iron, aluminum, uranium, and vanadium are precipitated. As the solution becomes basic the uranium and vanadium redissolve. It has been found that the increase to a 5% Na_2CO_3 solution will provide optimum results in operation. The tank contents are then run through a leaf filter. Filtrate is returned to the alkaline leach circuit tank while the sludge is repulped with an equal weight of water, and the slurry filtered on leaf filters. This filtrate is also returned to the alkaline leach circuit tank, while the iron-aluminum sludge is discharged to waste.

Two major effluents from the process go either to the Animas or to Lightner Creek. The main plant effluent, going to the Animas River, includes the vanadium filter tray effluent, the organic raffinate (barren acid liquor from solvent extraction), and the liquid primary tailings pond effluent. This waste stream also receives the iron-aluminum sludge. Redcake wash liquors join the vanadium filter tray effluent before it goes to the main plant effluent. Effluents from the final tailings pond, which receives the spent sands slurry, discharge primarily to Lightner Creek and at times to a flume going directly to the Animas.

The Mill Survey

Sampling of the various process streams within the mill was carried out over the period July 30 through August 5, 1958, with the cooperation of mill personnel. In order to properly characterize the wastes from the plant, it was necessary to collect representative samples at the following locations (See Figure 13 for station locations):

Table VIII

Sampling Stations in Mill

Station	Description
1.	The ore heads prior to addition of NaCl.
2.	Roaster calcines.
3.	Quench tank effluent
4.	Alkaline leach circuit tank effluent.
5.	Alkaline leach tank tails.
6.	Alkaline leach storage tank effluent.
7.	Filter press filtrate.
8.	Vanadium product.
9.	Yellowcake from filter press.
10.	Uranium product.
11.	Acid leach tank feed.
12.	Acid leach tails.
13.A	Final tails effluent to Lightner Creek.
13.B	Final tails to Animas River.
14.	Primary tails effluent.
15.	Raffinate from solvent extraction tanks.
16.	Iron-aluminum sludge.
17.	Vanadium filter tray discharge.
18.	The main plant effluent.

Samples were collected at Stations 1, 2, 8, 9, 10, and 16 by mill personnel. Personnel of the Public Health Service, Colorado State Department of Health, and the San Juan Basin Health Unit collected the samples at all other stations. Three composite samples were collected at each station over the following time periods:

Cycle A - 7:30 AM July 30 - 11:30 PM July 30 (16 hours).

Cycle B - 3:30 PM July 31 - 11:30 PM August 2 (56 hours).

Cycle C - 3:30 PM August 3 - 11:30 PM August 5 (56 hours).

Individual samples were taken hourly at Stations 1, 2, 3, 4, 6, 7, 13-A, 14, and 18. At Stations 8 and 9 a composite sample was made up by taking one sample per shift. At Station 10 a small vial of uranium product was collected once daily. Samples were taken at Stations 12 and 15 once every two hours. Flows at Stations 5, 11, 16, and 17 were intermittent, and samples were collected at these stations accordingly. At Station 13-B there was only a small intermittent flow during the first part of the survey. However, during Cycle C a large increase in this flow was noted, and samples were collected hourly during the 31.5 hours of flow.

Analysis of certain of the effluent samples has been completed, and results with interpretation are reported below. Analysis of many of the process stream samples and computation of results are not complete, and will be given in a subsequent report.

Chemical Use

Information regarding the amounts of various chemicals used in the mill processes was supplied by officials of the Vanadium Corporation of America, and is presented in Table IX.

Results of Mill Survey

Ore Processed and Products. During the period of survey within the uranium refinery at Durango, Colorado, ore was processed at a rate of about 514 tons raw ore per day. Figures supplied by mill personnel indicate that during this period the average output of vanadium product was 11,000 pounds per day as V_2O_5. Of this, about 5 per cent was dried redcake, the remainder being the fused vanadium concentrate. Over the same 8-day period 26,000 pounds of uranium concentrate as U_3O_8 were produced, for an average of 3,250 pounds per day.

In terms of radioactivity, it is estimated that the raw ore carried with it about 2.3 curies per day of gross alpha activity. Of this amount, about 1.7 curies per day were discharged to the tailings pond with sand and slimes solids, about 0.4 curie per day was included in the uranium concentrate, about 0.2 curie per day went out with the several effluents, and a negligible portion was included in the vanadium concentrate.

Effluents. Referring to the sampling stations indicated on Figure 13, Table X indicates the effluent flows and characteristics observed during the mill survey. Weighted average figures for flow rate, and dissolved and suspended solids concentrations are given for the three cycles of survey. As indicated earlier, Stations 14, 15, 16, and 17 all discharge to the main plant effluent, Station 18. In addition, during the survey period Station 18 included an average of about 90 gallons per minute of flow from the fresh water storage tank.

Table IX

Chemicals Used in Mill Process

Chemical	Use	lbs/ton ore Processed	lbs/day *
Inorganic			
Ammonium Sulfate	Washing redcake	3.16	1,620
Caustic (NaOH)	Precipitation of U_3O_8	1.37	705
Salt (NaCl)	Roasting-fusion	93.4	48,000
Soda Ash (bulk)	Fusion	2.92	1,500
Soda Ash (dense)	Leaching and Acid Liquor	122	62,700
Sodium Chlorate	Oxidizing V_2O_5 Liquor	0.68	350
Sodium Peroxide	Oxidizing Recycled Precipitation Liquor	0.047	24
Sulfuric Acid	Leaching and Precipitation	127	65,000
Hydrochloric Acid	Solvent Extraction	0.039	20
Phosphorus Pentoxide	" "	0.023	12
Potassium Permanganate	" "	0.14	71
Organic			
Kerosene	Solvent Extraction	0.72 **	370***
Heptadecanol	" "	0.084	43
Tributylphosphate	" "	0.63	325
Trifatty amine	" "	0.34	175

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* Based on 514 tons/day of ore processed.

** Gallons per ton of ore processed.

*** Gallons per day.

Table X

Mill Waste Flows

Station and Description	Average Flow, gpm	Average Solids Concentration, mg/l. Dissolved	Suspended
18 - Main Plant Effluent	270	35,400	5,550
14 - Primary Tails Effluent *	120	4,000	12,100
15 - SX Waste	32	178,000	4,670
16 - Fe-Al Sludge	9.6	11,400	31,800
17 - Vanadium Filter Tray Effluent	52	107,000	40
13-A - Final Tails Overflow to Lightner Creek **	71	13,000	11,000
13-B - Final Tails Overflow to Animas River ***	55	10,500	9,200

---

* Over 90 hours out of 128.

** Over 120 hours out of 128.

*** Over 62 hours out of 128.

Using the data presented in Table X for Stations 18, 13-A and 13-B, it has been estimated that during the mill survey period a total of 14.9 tons per day of suspended solids were discharged to Lightner Creek and the Animas River. Specifically, the figures are 9.0, 4.4, and 1.5 tons per day for Stations 18, 13-A, and 13-B, respectively. The total of 14.9 tons per day represented nearly three per cent of the ore processed during this period.

Gross Radioactivity. Table XI indicates the average gross alpha and beta radioactivity of the mill waste streams for the mill survey period. In addition, the gross activities of the crushed ore and of the vanadium and uranium concentrates are given in Table XII.

The data of Tables X and XI provide a basis for estimating the amount of radioactivity discharged daily during the mill survey in undissolved form. For Stations 18, 13-A, and 13-B, respectively, average daily discharges of suspended gross alpha radioactivity were 99, 69, and 3 millicuries per day, for a total of 171 mc/day.

Uranium. As indicated earlier, a few selected effluent samples have been analyzed for uranium. While the results cannot be considered as representative averages for the entire mill survey period, they provide useful information, and are reproduced in Table XIII below. Upon completion of analysis of the remainder of the samples a later report on this subject will be issued, in which both uranium and radium balances will be available. In addition to the data of Table XIII, uranium analyses and interpretation have been made for Animas River samples, and will be discussed in Section VI.

Using the waste stream flows given in Table X, and adding the resulting figures for the three effluents, it is evident that as much as 160 pounds per day of dissolved uranium may leave the mill as liquid wastes to the Animas River. Further data on this subject is given in Section VI, based upon river sampling.

Radium. Selected effluent samples have been analyzed for their radium content, and the results are reproduced in Table XIV.

The average results are 108, 180, and 481 μμg/l. (micromicrograms per liter) of dissolved radium at Stations 18, 13-A, and 13-B, respectively. These data, while indicating ranges to be expected, cannot be considered as representative averages for the survey period. In a subsequent report on the mill process a radium balance will be given and representative average radium concentrations will be available. Considerably more radium data are provided by the Animas River samples, and are given in Section VI.

Using the averages of the above data, and the flows of Table X, it appears that the refinery discharged about 0.30 milligrams per day of dissolved radium during the survey period; using the flows of Table X and the maximum observed radium concentrations, the figure would be about 0.80 mg/day.

Based upon the rate of ore processing, the amount of uranium in the ore, and the assumption of radioactive equilibrium between uranium and radium in the ore, it can be estimated that the mill takes in about 400 mg/day of radium with the raw ore.

Table XI

Gross Radioactivity of Mill Wastes

	Gross Radioactivity, $\mu\mu c/l.$*			
	Alpha		Beta	
Station	Dissolved	Suspended	Dissolved	Suspended
18	4,500	67,000	20,500	44,000
14	8,400	61,500	13,400	184,000
15	58,500	31,800	135,500	27,300
16	10,700	252,000	28,800	134,000
17	3,300	--	9,700	--
13-A	65,800	190,000	112,000	173,000
13-B	41,200	18,500	64,000	17,300

---

* Average Value for mill survey period.

Table XII

Gross Radioactivity of Ore and Products

	Gross Radioactivity, $\mu\mu c/gm.$ *	
Station and Description	Alpha	Beta
1 - Crushed Ore	4,950	5,960
8 - Vanadium Product	120	230
10 - Uranium Product	281,000	213,000

---

* Average Value for mill survey period.

Table XIII

Uranium in Waste Streams

Station	Dissolved Uranium mg/l.
18	33
	6
	3
13-A	57
	51
13-B	39

Table XIV

Radium in Waste Streams

Station	Dissolved Radium μμg/l.
18	92
	124
	105
	115
	160
	115
	44
13-A	58
	154
	71
	440
13-B	140
	822

Estimates of the quantity of radium discharged to the Animas River daily in the undissolved state are of interest. It has been shown that the refinery was discharging as suspended solids nearly three per cent of its processed ore, and that the daily radium intake with the ore was about 400 mg/day. Using these figures directly, it results that about 12 mg/day of radium reached the river in suspended or undissolved form. On the other hand, this figure appears to be rather conservative in the light of other data presented earlier. It has also been shown that during the mill survey period about 171 mg/day of undissolved gross alpha activity was discharged. Although direct analytical results are not yet available, the radium fraction of this gross alpha activity would be at the least 10 per cent, and more probably 20 to 25 per cent. (The latter figure is borne out in Section VI on the basis of the radium:gross alpha ratio of river muds collected below the mill.) Hence, on this basis it appears that at least 17 and more probably 35 to 40 mg/day of radium were discharged in the undissolved state during the mill survey period. This latter estimate is also more in keeping with the data regarding the usual radium:gross alpha ratio in natural soils. It is estimated, therefore, that during the mill survey an average of 30 mg/day of radium in undissolved form was discharged to the river. That this figure has significance in terms of the river water quality will be discussed in subsequent sections dealing with the river survey data.

Chemicals. Selected effluent samples have been analyzed for various chemical constituents by usual methods. The results of these analyses are indicated in Table XV. While they do not represent long term averages, it is believed that these results do provide an adequate indication of the chemical quality of the mill effluents.

According to the data given in Table IX regarding chemical usage at the mill it can be estimated that the following quantities are used daily:

Sodium	(Na)	46,000 lbs.
Chloride	(Cl)	29,000 "
Sulfate	(SO_4)	68,000 "

(These figures have not been reduced to account for any impurities in the chemicals as received at the mill.) These data provide a basis for balancing chemical use against chemicals wasted, thereby providing at least a rough check on the accuracy of the waste flow and chemical quality figures.

Using the effluent flows provided in Table X and the chemical concentrations from Table XV, it can be shown that the quantities of basic chemicals leaving the mill in the effluents were, during the survey, approximately:

Sodium	:	34,400 lbs. per day
Chloride	:	20,000 " " "
Sulfate	:	65,500 " " "

Considering the variability of the effluents, and that only selected samples were analyzed for chemical components, as well as the fact that the above figures represent only the dissolved chemicals, the agreement between these figures and the amounts used daily is considered satisfactory. In Section VI it will be shown that the chemical quality of river water samples verifies the above figures.

In interpreting these and other data presented in this Section, it should be kept in mind that plans in 1958 were to increase mill capacity toward 700 to 750 tons of ore per day versus the 514 tons per day considered here.

Table XV

Chemical Components of Mill Wastes *

Chemical	Concentration, mg/l. Station 18	Station 13-A
Sulfate	18,100	6,100
Chloride	5,800	1,060
Sodium	10,500	300
Iron	0.3	48
Manganese	40	13
Zinc	42	25
Copper	11	29
Beryllium	0.5	6.4
Arsenic	0.14	4.0
Selenium	0.06	--
Cadmium	0.3	0.8
Lead	< 0.04	0.13
Vanadium	0.08	9.0
Flouride	10.5	10.5
Mineral Acidity	0	2,600
Total Acidity	260	4,620
Total Hardness	2,400	3,200

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* Aqueous Portions

SECTION VI

RIVER AND ENVIRONMENTAL SURVEY RESULTS

As indicated earlier, the data presented in this Section represent primarily the survey of the summer of 1958, and does not include data later than October 1, 1958, unless directly noted. As will be indicated specifically where pertinent, the Animas River flows for the survey period are those shown in Section II, Table VI.

River Water

River water samples were collected to make eight weekly composites at each of nine sampling stations as noted in Section III. Most of these samples have been analyzed for various constituents, and results are noted below.

Gross Radioactivity. Table XVI indicates the gross alpha and beta radioactivity of the river waters. Suspended solids concentrations were very low at all of the background locations, that is, at Stations 1, 3, and 12. At these locations the gross radioactivity of the river waters was generally low and comparable. Background radioactivity at the three locations averaged 3, 2, 38, and 3 μμc/l. of dissolved and suspended alpha and dissolved and suspended beta, respectively.

Station 11 was immediately below Station 13-A of the mill survey, or the final tails discharge to Lightner Creek, while Station 10 was just below the main plant effluent to the Animas. Considerable quantities of suspended radioactivity were present at each location, and the dissolved

Table XVI

Gross Radioactivity of River Water *

Station	River	Mileage Below Mill	Gross Radioactivity, μμc/l. Alpha Diss.	Alpha Susp.	Beta Diss.	Beta Susp.
1	Animas	-1.0	2	< 1	40	6
12	Lightner Cr.	-0.2	5	~ 0	30	~ 0
11	Lightner Cr.	0.03	190	3,200	530	3,700
10***	Animas	0.05	150	5,200	270	6,600
2	Animas	2.0	85	35	115	55
4	Animas	23	60	15	130	25
3**	Florida	-	3	3	40	~ 0
5	Animas	28	65	15	150	32
6	Animas	59	30	3	80	10

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* Average results for the eight weeks of survey.

** Tributary stream joining Animas about 23.1 miles below mill.

*** Not an adequately representative cross-sectional sample.

alpha and beta activities were significantly increased above background. Station 2, two miles below the mill, had an automatic sample collector. It should be noted that the bulk of the suspended radioactivity had disappeared at Station 2, having settled to the river bed above that location. Stations 4, 5, and 6, progressively further downstream from the mill, showed some slight further decrease of dissolved alpha activity, but remained above the natural background radioactivity levels. Using the flows of Section II, Table VI, the average dissolved gross alpha radioactivity passing Stations 2 and 5 was about 80 and 70 mg/day, respectively.

Radium. Dissolved radium analyses were performed on all composite river water samples. The results are presented in Table XVII.

Table XVII

Dissolved Radium Content of River Water

Station	Dissolved Radium, μμg/l. Average	Dissolved Radium, μμg/l. Range	Dissolved Radium, mg/day
1	0.6	0.3 - 1.0	0.54
12	0.3	0.1 - 0.4	-
11	49	15 - 86	-
10 *	40	21 - 56	-
2	12.6	9.0 - 19.0	11.5
4	7.2	5.2 - 8.7	7.2
3	0.3	0.0 - 1.1	0.02
5	7.6	6.0 - 10.0	8.0
6	2.9	2.4 - 3.4	1.6

---

* Not an adequately representative cross-sectional sample.

Dissolved radium as mg/day passing a given sampling station was obtained by use of the individual radium concentrations and the river flows of Table VI, Section II.

The dissolved radium concentration ranged from 6 to 30 per cent of the dissolved gross alpha activity at the various stations. At the locations downstream from the mill, this percentage was at a maximum near the mill and diminished steadily as the distance of the sampling station below the mill increased.

In terms of quantities it is of interest to note that between Stations 1 and 2 about 11.0 mg/day of dissolved radium was added to the river water. This quantity decreased only slightly between Station 2 and the Colorado-New Mexico State Line, Station 5, the Florida River adding a negligible amount. Below the State line large quantities of Animas River water are used for crop irrigation. As a result, the total flow in the river was markedly reduced by the time it reached Station 6, Farmington. Also, return irrigation flow tended to dilute the remaining river water and thus helped to reduce radium concentrations. By these effects, the quantity of radium in mg/day passing Station 6 was markedly less than at the State line. This reduction may also have been aided by radium removal from the water by biological uptake, and possibly by precipitation.

As noted in Section V, the quantity of dissolved radium released by the direct mill effluents cannot account for the quantity found in the water at Station 2, just 2.0 miles downstream. Measured dissolved radium discharges in the mill effluents amounted to only 0.3 to 0.8 mg/day, whereas an observed gain of 11.0 mg/day was noted at Station 2. It is quite doubtful that seepage from the tailings piles could account for this large quantity of radium at Station 2. On the other hand, the mill discharged larger quantities of radium in the undissolved state. As noted previously, these discharges amounted to probably 30 to 40 mg/day. It has been seen that the bulk of these undissolved mill solids settled out in the river above Station 2. This daily discharge of undissolved radium, depositing above Station 2, may be viewed as forming a reservoir of radium for subsequent dissolution and appearance as dissolved radium at Station 2 and downstream. This point of radium solubility will be detailed further in the discussion of river mud data.

Uranium. Selected river water samples from the summer survey of 1958, and from a later resurvey in April 1959, have been analyzed for dissolved uranium, and the results are presented in Table XVIII.

Thus, it may be seen that during the summer of 1958 the average quantity of dissolved uranium passing Stations 2 and 5 was 308 and 312 pounds per day, respectively. In April of 1959 only grab samples of river water were collected, as contrasted to the weekly composites of the 1958 survey. Hence, the effects of intermittent waste discharges is expected to be more evident in the 1959 data at Station 2. These data therefore indicate momentary quantities of dissolved uranium of about 85 and 190 pounds per day passing Stations 2 and 5, respectively. Naturally occurring concentrations of dissolved uranium are low, as indicated by the samples of April 1959 at Stations 1 and 3, and the quantities passing the stations below the mill can be said to have essentially all arisen as a result of the mill effluents. The best available data, because of its composited nature and its duration of sampling, are the 1958 summer data for Stations 2 and 5, indicating 200 to 400 pounds per day of dissolved uranium in the river below the mill. The data of 1959, together with the mill effluents reported in Section V, indicate that these figures are reasonable.

Table XVIII

Dissolved Uranium Content of River Water

Station	Date	Flow,* cfs	Dissolved Uranium µg/l.	µµc/l.	lbs/day
2	week 1 - 1958	505	160	53	435
	" 3 - "	390	120	40	252
	" 7 - "	295	150	50	238
5	" 1 - "	605	140	47	455
	" 3 - "	450	130	43	315
	" 7 - "	295	110	37	175
1	April 1959	325	0.4	~ 0	~ 1
2	" "	330	47	16	84
3	" "	~16	3.1	1	~ 0
5	" "	220	160	53	190

---

* See Section II, Table VI

It is also of interest to note that the quantities of uranium present at Stations 2 and 5 add materially to the dissolved gross alpha activity of the water. Thus, on the average, it is indicated that of the observed dissolved gross alpha activities at Stations 2 and 5, (See Table XVI) about 45 µµc/l. and 40 µµc/l. were due to dissolved uranium. In another sense, about 60 per cent of the dissolved gross alpha activities at Stations 2 and 5 was due to dissolved uranium.

Strontium. Selected samples of river water were analyzed for strontium-90 and strontium-89. In brief, three of the composite river water samples from Station 1 and three from Station 5 showed no essential difference. These six determinations indicated an average of 0.8 μμc/l. of strontium-90, with a range of 0.5 to 1.15 μμc/l. Strontium-89 analyses in two of these samples amounted to 3.2 and 7.5 μμc/l.

Chemicals. Table XIX indicates the chemical quality of the Animas River during the summer of 1958. These data represent averages for the 5th and 6th weeks of the summer survey, and river flows corresponding to that period for the stations noted may be found in Section II, Table VI. Using the corresponding river flows, it is of interest to compute the quantities of certain chemicals involved. According to these computations based on river flows and observed concentrations, it is indicated that

47,000 lbs/day of sodium,

25,000 lbs/day of chloride, and

76,000 lbs/day of sulfate

are added to the Animas River above Station 2 by the mill. These figures are in excellent agreement with the known amounts of chemical used daily at the mill, as indicated in Section V, indicating that the flows of Section II and the data of Table XIX are within satisfactory limits of accuracy.

The data of Table XIX also indicate that the quantities of sodium, chloride, and sulfate persist in the river to the State line, and do not diminish appreciably. Quantities of other materials released in the mill effluents were, according to Table XIX, too small generally to be reflected in increased river concentrations. Exceptions to this are arsenic, vanadium, and possibly selenium and zinc, for which additions by the mill effluents, while small, were detectable.

Mill Effluents. Following the in-plant mill survey, effluent samples were collected routinely for the rest of the summer period. Weekly composites were made up of daily grab samples. Effluent flows were not obtained to correspond to these samples. The gross radioactivity of these effluents is given in Table XX. The average dissolved alpha and beta radioactivities were 6,800 and 19,200 μμc/l., respectively, for the main plant effluent, and 37,100 and 88,300 μμc/l., respectively, for the final tails effluent to Lightner Creek. The average suspended gross alpha and beta radioactivities were 44,100 and 60,500 μμc/l., respectively, for the main plant effluent, and 14,000 and 16,000 μμc/l., respectively, for the final tails effluent to Lightner Creek. Bearing in mind the inherent wide variability of suspended solids discharges, and that the data of Table XX represent only daily grab samples, these data are in satisfactory agreement with those obtained during the in-plant mill survey.

Table XIX

Chemical Content of River Water

Chemical	Concentration, mg/l. Station 1	Station 2	Station 4	Station 5
Sulfate	113	151	160	141
Chloride	21.6	33.8	38	30.8
Sodium	24.8	48	44	48
Iron	< 0.02	< 0.02	< 0.02	< 0.02
Manganese	< 0.075	< 0.075	< 0.075	< 0.075
Zinc	0.040	0.070	< 0.019	< 0.019
Copper	< 0.025	< 0.025	< 0.025	< 0.025
Beryllium	0.085	0.04	< 0.01	0.01
Arsenic	< 0.016	0.056	0.044	0.056
Selenium	< 0.002	0.0025	0.003	0.0025
Cadmium	< 0.004	< 0.004	< 0.004	< 0.004
Lead	< 0.02	< 0.02	< 0.02	< 0.02
Vanadium	< 0.002	0.008	0.006	0.006
Flouride	0.44	0.42	0.44	0.42

Coliform Bacteria. At three separate times during the 1958 summer survey, a series of samples was collected for bacteriological analysis. The results of this work are indicated in Table XXI.

These data indicate the general effects of additions of domestic sewage in the Durango area and in New Mexico. No serious pollution problem is indicated by the data, except insofar as the raw river water may be used for domestic purposes. These laboratory analyses were performed by personnel of the San Juan County Health Department at Farmington, New Mexico.

Table XX

Gross Radioactivity of Mill Effluents

		Gross Radioactivity, µµc/l.			
		Alpha		Beta	
Station	Date	Dissolved	Suspended	Dissolved	Suspended
18	Week 3, 1958	4,460	21,000	10,400	32,100
	" 4 "	6,410	56,000	17,600	73,500
	" 5 "	7,430	17,400	22,500	46,100
	" 6 "	7,120	104,000	20,700	122,000
	" 7 "	-	41,000	-	60,000
	" 8 "	8,610	25,400	25,000	29,700
	Mean:	6,800	44,100	19,200	60,500
13-A	Week 3, 1958	37,800	13,100	119,000	19,100
	" 4 "	56,200	23,800	115,000	21,300
	" 5 "	20,000	7,700	41,600	9,900
	" 6 "	34,500	11,600	78,000	13,700
	Mean:	37,100	14,000	88,300	16,000

Table XXI

Bacteriological Quality of River Water

	MPN/100 ml. *		
Station Location	8/13/58	8/26/58	9/10/58
Above Durango, Colorado	13	17	33
Below " "	130	350	920
Colorado-New Mexico State line	79	140	110
Above Farmington, New Mexico	220	56	1600
Below " " "	180	140	240

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* Most Probable Number of Coliform Bacteria per 100 ml. of sample.

Dissolved Oxygen and Biochemical Oxygen Demand. In order further to measure the effects of additions of domestic sewage, Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) analyses were performed on three separate series of samples. These series of DO samples were collected in each case on the day of collection of the bacteriological samples, and at the same locations DO's were fixed in the field and titrated in the laboratory. BOD's were collected a day earlier than DO's, and returned to the laboratory and placed in the incubator immediately. For the first collection (August 12) of BOD's a 10-day time series was performed for each Station in order to evaluate the nature of the oxygen demand. For the second BOD collection (August 25) the first and fifth-day demands were determined, and for the third collection, one-, two-, and five-day demands were determined. The results of these analyses are indicated in Table XXII (DO) and Table XXIII (BOD). For the BOD's, the 5-day BOD, the ultimate first-stage BOD, and the BOD velocity constant, k_1, are reported for the first collection, while only the 5-day values are presented for the latter two sample collections.

The effects of domestic sewage added at Durango, while not large, are clear from Table XXIII, about 1.5 to 2.0 mg/l. of BOD being added. The DO was not depressed, however, but showed a net gain (Table XXII) of 2.0 to 4.0 mg/l. This was due to the prolific attached algal growths occurring in the river below Durango. At this location some supersaturation of DO occurred.

Table XXII

Dissolved Oxygen of River Water

Station & Location	Dissolved Oxygen, mg/l. 8/13/58	 8/26/58	 9/10/58
Above Durango, Colo.	7.4	7.6	7.7
Below " "	11.9	10.4	9.7
Colo.-N. M. State Line	8.1	9.4	8.5
Above Farmington, N. M.	8.8	9.2	8.8
Below " N. M.	5.9	6.7	5.9

Table XXIII

Biochemical Oxygen Demand of River Water

Station & Location	Biochemical Oxygen Demand, mg/1.				
	8/12/58			8/25/58	9/9/58
	5-day	Ultimate	k_1/day	5-day	5-day
Above Durango, Colo.	1.0	1.3	0.13	1.3	0.8
Below " "	2.8	3.4	0.14	2.4	1.7
Colo.-N. M. State Line	1.6	2.4	0.11	2.0	1.3
Above Farmington, N. M.	2.0	2.5	0.15	1.5	1.2
Below " "	4.8	5.7	0.14	4.6	4.8

This DO diminished slightly to the State Line, as did the BOD, but remained near saturation. There was little further change until Farmington was reached, at which location about 3.0 mg/1. of BOD was added. A corresponding drop in the DO occurred below Farmington, to a low of about 6.0 mg/1.

Remarks. In interpreting the results of the river water and other analyses, it should be noted that immediately prior to the summer survey of 1958 a major spring flood occurred on the river. Specifically, in early June the river flow at Durango reached 7,000 cfs, and did not return to lower levels (below 1200 cfs) until early July. As a result, the river bed was rather thoroughly flushed immediately prior to the survey. It should also be recalled that the Vanadium Corporation of America began a new process, acid leach-solvent extraction, just prior to the river survey.

Water Plants

As noted in Section III, composite samples of both raw and treated water at the Aztec and Farmington, New Mexico, water treatment plants were collected during the survey. Similar samples of raw water were collected at the Shiprock, N. M. water treatment plant. All of these water treatment plants employed conventional methods of water treatment, including sedimentation, addition of chemicals, rapid sand filtration and chlorination. None of them used water softening. As has been noted, Aztec obtained its raw water supply from a ditch diversion taking water from the Animas about 3 miles above Aztec. Farmington's water supply was in part from a ditch taking water from the Animas above Aztec, and in part directly from the Animas at Farmington. Shiprock took its water part of the time from the San Juan via a ditch diversion 12 miles east of the town and directly from the river near Shiprock at other times. Details of sample collection and compositing have been noted in Section III.

In presenting the data regarding the quality of domestic water at New Mexico locations, the data regarding quality at the Colorado-New Mexico boundary is included because it most nearly reflects the character of water available to the substantial number of New Mexico users of raw Animas River water. It will be recalled that an estimated 1,845 people in New Mexico are in this category, some taking water directly from the river and others from irrigation ditches, with some using cisterns for raw water storage and some using filters prior to storage.

Gross Radioactivity. The gross alpha and beta radioactivity of raw and treated water at the various points of use in New Mexico is presented in Table XXIV.

Table XXIV

Gross Radioactivity of Water Supplies*

		Gross Radioactivity, μμc/l.			
		Alpha		Beta	
Station**	Description	Dissolved	Suspended	Dissolved	Suspended
5	Colo.-N.M. State Line	65	15	150	32
7R	Raw water, Aztec, N. M.	36	10	90	36
7T	Treated " " "	38	1	78	4
8R	Raw " Farmington,"	32	4	90	11
8T	Treated " " "	32	-	67	-
9R	Raw " Shiprock, "	8	-	50	-

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* Average results for eight weeks of summer survey, 1958.

** The letter R denotes raw water, and T denotes treated water.

Suspended solids concentrations in the Farmington treated water and in the Shiprock raw water supply were very low, and dependable analyses could not be made without some difficulty. The amount of radioactivity in suspended form in these waters was negligibly small. In terms of gross radioactivity, it may be noted that there was no appreciable removal of dissolved alpha activity during treatment at either Aztec or Farmington, and only slight removal of dissolved beta activity.

Radium. All of the domestic water supply samples, raw and treated, have been analyzed for radium, and the results are given in Table XXV.

Table XXV

Radium Content of Water Supplies

Station	Dissolved Radium, μμg/l. Average	 Range
5	7.6	6.0 - 10.0
7R	3.4	2.3 - 4.7
7T	3.6	2.7 - 4.5
8R	2.8	1.6 - 3.4
8T	2.6	2.1 - 3.2
9R	0.4	0.1 - 0.7

It is apparent from Table XXV that the water treatment plants at Aztec and Farmington do not remove dissolved radium from the raw water during treatment with any dependability or efficiency. Whatever amount of dissolved radium occurs in the raw water must be expected to pass unchanged to the treated water. From the gross radioactivity data of Table XXIV, this is also apparently true for other alpha emitters.

In terms of natural background concentrations of dissolved radium (See Table XVII), the dissolved radium content of the raw waters at Aztec and Farmington were 5 and 6 times higher than background amounts as measured on the Animas at Station 1, and 10 times higher than background as measured on the Florida River, on Lightner Creek, or for that matter on the San Juan below its confluence with the Animas (Station 9R). During the 1958 survey period the radium content of the raw and treated waters at Aztec and Farmington approached the MPC for radium.(8),(9) In terms of population exposure, it must be borne in mind, as indicated earlier, that the summer of 1958 was relatively wet in terms of flows in the Animas, and that the available dilution for wastes was therefore somewhat higher than in other years and other seasons. This effect will be discussed in some detail at a later point.

As regards raw water users below the Colorado-New Mexico State line, the quality of water at Station 5 represents the best available estimate of their raw water quality. As may be seen, it averaged 7.6 μμg/l. of dissolved radium, or about 12 to 25 times the natural background amount, and about twice the allowable concentration, or MPC.(8)(9) As has been noted, the available dilution at Durango was higher during the survey than in other summers. Estimates of average annual exposures in terms of river flow expectancies will be discussed further in Section VIII.

It is also pertinent to note that radium concentrations noted here reflect the effects of irrigation water diversion and return. As indicated earlier (Table XVII), this apparently resulted in marked reduction of dissolved radium between the State line and Farmington. Uptake by aquatic biota may have assisted in this reduction. In any case, it is quite doubtful that the radium concentrations below the State line would be so significantly reduced during the non-irrigation seasons. While it is not possible to predict with certainty on this point, it appears likely that during the non-irrigation part of the year radium concentrations at the Aztec and Farmington raw water intakes will much more nearly approach the concentrations observed at the State line. This is, in fact, borne out to good degree by the data regarding radium concentrations above the State line. Referring to Table XVII, it is seen that there is essentially the same amount of radium in the water at Stations 4 and 5. Although some irrigation water is diverted in Colorado, most is taken below the State line, and the return irrigation water flow above the State line is only slight. Hence, it appears that irrigation practice in New Mexico during the warmer months aids materially in protecting the New Mexico water supplies as regards their radium content.

Filter Sands. Samples of sand from the filters at the Aztec, Farmington, and Shiprock water treatment plants were collected three times during the summer and analyzed for gross radioactivity and for radium. The results are noted in Table XXVI. It is apparent that the filter sands in use at Aztec contained relatively larger quantities of radium. They contained about six times the amount in those at Farmington. The latter contained about three times the amount of radium found in river muds (see below) above the uranium mill on the Animas and on the Florida River.

It is of interest to note from Table XXV that, although the difference is slight, the treated water for Aztec showed slightly more dissolved radium on the average, than did the raw water. The reverse was true for Farmington. This and the data of Table XXVI indicate the likelihood that radium trapped in water plant sand filters will dissolve out in part into the treated water.

Table XXVI

Radioactivity of Filter Sands

Station	Description	Radioactivity, μμc/gm.* Gross Alpha	Gross Beta	Radium	Radium Range
7	Aztec Water Plant	45	117	27	25 -29.6
8	Farmington Water Plant	32	125	4.7	3.3- 5.6
9	Shiprock Water Plant	40	123	2.6	2.6

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* Dry Weight.

Strontium. Five pairs of composite raw and treated water samples from Aztec and Farmington were analyzed for Strontium-90. The raw waters averaged 1.6 μμc/l, with a range of 1.0 to 2.9 μμc/l, while the tap waters averaged 1.0 μμc/l, with a range of 0.3 to 1.8 μμc/l. These levels were well below the MPC of 80 μμc/l.(8),(9)

River Muds

Samples of river mud and silt were collected every other week during the summer survey, and the results are reported below. It should be noted that these are cumulative samples, in the sense that silts and muds accumulate during periods of low stream runoff and velocity. In this same sense it should be recalled that during June and early July, 1958, river flows were high and scouring velocities existed, with the result that river muds and silts were to a large degree scoured from the stream bed and carried downstream and into the San Juan. Hence much of the data presented here represents accumulations over a relatively brief period of one to two months.

Gross Radioactivity. Table XXVII presents the average gross alpha and beta radioactivity data for the river mud samples. A total of four samples is involved for each station, one every other week for the eight survey weeks. The higher gross radioactivity data were found in the earliest samples at each Station.

Table XXVII

Gross Radioactivity of River Muds

Station	Mileage Below Mill	Gross Radioactivity, $\mu\mu c/gm$* Alpha	Beta
1	-1.0	18	110
2	2.0	1,250	1,350
3**	-	17	70
4	23	395	450
5	28	285	430
6	59	42	83

---

* Dried weight.

** Tributary Stream, entering the Animas at about Mile 23.1 below the mill.

Analysis of one sample from Station 11, below the mill on Lightner Creek, yielded gross alpha and beta activities of 2,700 and 2,600 $\mu\mu c/gm$, respectively. Analysis of a sample from the mill side of the river at Station 10 (immediately below the Main Plant Effluent) yielded results about 10 times higher than those for Station 11. As may be seen, the average alpha activity of muds at Station 2 was 70 times higher than the natural alpha background, while the average beta activity at this station was 12 times higher than the natural beta background, as measured at Stations 1 and 3.

Radium. Samples from the third and fourth mud collections were analyzed for their radium content, for Stations 1, 3, 4 and 5, and for the fourth collection also at Stations 2 and 6. The results are as shown in Table XXVIII. Analyses for Stations 10 and 11, and for the earlier collections are not completed at this time.

As may be seen from Table XXVIII, the natural background radium content of river muds in the Animas Basin is about 1.7 $\mu\mu g$ of radium per gram of dry mud. The single result now available for Station 2 is 70 times this background amount. The average results for Stations 4 and 5 are 30 times and 12 times the background radium.

Table XXVIII

Radium Content of River Muds

Station	Radium, μμg/gm*	
	Mean	Range
1	1.7	1.7- 1.8
2	115.	-
3	1.7	1.1- 2.4
4	48	46 -49
5	21	19 -23
6	3.7	-

---

* Dried weight.

On the average of the individual results, the radium content of muds at Stations 1 and 3 was 9 per cent, while at Stations 2, 4, 5 and 6 it averaged 23 per cent of the gross alpha activity. Hence it can be concluded that the deposited waste solids from the mill had a radium: gross alpha ratio of at least 0.25. Recalling from Section V that during the mill survey period an average of about 170 mg/day of suspended gross alpha activity was discharged, it follows that during that time the suspended radium discharge can be estimated at about 40-50 mg/day.

Now it has been noted earlier that the amount of dissolved radium found at Station 2 on the river was much higher than that found in the mill effluents combined. Specifically, it was estimated that of a net gain above background at Station 2 of 11.0 mg/day of radium, no more than 1.0 mg/day was found as dissolved radium in the mill effluents. It should be emphasized that the data for Station 2 are quite consistent and represent the average of two months of composite sampling, whereas the effluent data are more sparse at present and must admit of a wider range of possible error for long term averages. Nevertheless, it is clear that a substantial portion if not most of the dissolved radium found at Station 2 has its source in the deposited solids on the river bed above that Station.

Dissolution of Radium From Mud. In order to obtain some information as to the extent to which river muds may serve as a source of dissolved radium, the preliminary experiments described below were performed. The test material was a mud sample available from earlier studies on a different stream, but even though the results are not specific for the Animas River, they clearly indicate general effects and trends to be expected.

The mud sample contained 2,100 μμg of radium per gram of dry mud. In the first test series, 1.00 gm of this mud was mixed with 200 ml of water and allowed to stand for 15 additional minutes. The mixture was then centrifuged, decanted, and retreated with an additional 200 ml. of water. The process was repeated through six decantations, and the resulting liquid portions were analyzed individually for dissolved radium. The second test series was the same, except that a 0.10 gm mud sample was used. A third series was the same as the first, except that the mixture was stirred for 23 hours before centrifuging.

Series I and II yielded very similar results in terms of μμg Ra in the decanted solutions, even though the source mud quantities differed by a factor of 10. In both cases the radium content of the decanted solutions diminished progressively from an initial high value to about 2.0 μμg in the fifth and sixth decantations. This was about 25 per cent of the first decantation content, and it appeared to be near an equilibrium in the sense that further decantations would contain not much less than 2.0 μμg Ra. In the case of Series I this amounted to about 0.1 per cent of the original source of radium, whereas for Series II it was about 1.0 per cent. Hence, within the range of the experiment, the weight of radium dissolved depended primarily on the volume of liquid brought into contact with the mud, rather than upon the quantity of radium present in the source mud.

All six decantations for Series III contained essentially identical quantities of radium, and averaged 8.2 μμg Ra, or at least four times the terminal or equilibrium value for Series I and II. Hence, stirring and the longer contact period changed the results markedly in that there was no progressive change in the radium content with successive volumes of water. The 8.2 μμg of radium amounted to about 0.4 per cent of the original amount of radium in the mud.

Thus, these experiments demonstrate that radium-bearing muds act as radium reservoirs and can be expected to contribute dissolved radium to water with which they have contact. The degree to which radium will become dissolved in any case will depend a good deal, apparently, upon the intimacy and duration of water-mud contact, or, in the case of streams, upon the velocity and degree of turbulence and bottom scour. In the laboratory it has been found that from 0.1 to 1.0 per cent of the radium in mud may be dissolved out with brief mixing. Further experiments and computations for the case of the Animas are being performed, but it is believed that the above range is not unreasonable for that case. Considering a daily deposit of 30 to 40 mg of radium above Station 2, and the above range of solution percentages, it is a simple matter to demonstrate the accumulation of at least a gram of radium in the muds and the presence as a result of 10 mg/day of dissolved radium passing Station 2. Conservative computations based upon the data of Table XXVIII indicate this much undissolved radium to be present in the muds above Station 2.

Strontium. Three samples of river mud were analyzed for strontium-90, and the average result was 0.4 μμc of strontium-90 per gram of ashed mud. Two samples of farm topsoil indicated a slightly higher amount of strontium-90, or about 0.6 μμc per gram of ash. All five of these samples were scanned en masse for significant gamma photopeaks. This test indicated the presence of radium-226, ruthenium-103 and -106, zirconium-95 and niobium-95, and potassium-40. Only the definite presence of these radioisotopes was confirmed for the sample group, and numerical concentrations were not determined.

Aquatic Biota

Samples of aquatic algae and bottom-dwelling insects were hand-collected every other week during the summer survey, and have been analyzed for their radioactivity content. Fish samples were collected by personnel of the Colorado Department of Game and Fish in August, 1958, as well as later in the year and in early spring of 1959. The results of analysis of these samples are noted below.

Gross Radioactivity. The average gross alpha and beta radioactivity of the attached algae and insects for the summer, 1958, is indicated in Table XXIX. The gross alpha activity of algae at Station 2 was 100 times or more greater than the natural alpha background, and 50 times greater at Station 4. At the State Line (Station 5) the gross alpha activity of algae was still 30 times background, and diminished to about 5 times background at Farmington (Station 6). Radioactivity of the bottom insects was quite similar.

Table XXX gives the results of gross radioassay of fish samples. Only the average results for minnows are presented. The few flesh and bone samples for larger fish have not yet been analyzed for radium or other radionuclides, and sufficient gross assay data are not available to be adequately representative. These samples will be discussed in a later report.

These minnows were analyzed in entirety by being homogenized, and therefore the results include any silt present in the gut. The results generally show the same picture of increase of gross activity as seen for the algae and aquatic insects. A later fish collection of the Spring of 1959 shows generally somewhat lower results, by a factor of abour four.

Radium. Table XXXI indicates the results of radium analysis of the algae and aquatic insects. Radium analyses are not yet available for fish samples.

Table XXIX

Gross Radioactivity of Aquatic Biota

River Sampling Station	Gross Radioactivity, μμc/gm*			
	Algae		Insects	
	Alpha	Beta	Alpha	Beta
1	23	450	30	880
2	3,910	5,760	1,820**	4,110**
3	33	640	11	430
4	1,520	2,160	1,190	2,260
5	910	2,010	360	830
6	120	290	75	400

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* Ash weight.

** Single sample

Table XXX

Gross Radioactivity of Minnows

River* Sampling Station	Kind of Minnows Present	Gross Radioactivity, μμc/gm			
		Ash Weight		Live Weight	
		Alpha	Beta	Alpha	Beta
1	Speckled dace, sculpin, fathead, sucker	3.3	75	0.11	2.5
2	Speckled dace, sculpin, fathead, br. trout	290	380	10.6	12.7
5	Speckled dace, sculpin, sucker	90	150	3.3	5.7

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* Approximate location.

Table XXXI

Radium Content of Aquatic Biota

River Sampling Station	Radium, μμg/gm*			
	Algae		Insects	
	Average	Range	Average	Range
1	4.8	2.8 - 10.0	4.2	2.5 - 7.0
2	390	180 - 530	71	----
3	4.3	2.0 - 8.2	3.4	1.4 - 5.7
4	150	96 - 210	160	----
5	90	57 - 115	68	----
6	26	13 - 46	15	12 - 17

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* Ashed Weight.

The algae data represent all of the samples collected, whereas the aquatic insect samples have not all been analyzed. In addition, aquatic insects were not obtainable in sufficient quantity for analysis at Station 2 after the first collection. Insect data for Stations 1 and 3 (background) represent three collections; two samples are involved at Station 6, and only a single analysis is available at this time for Stations 2, 4 and 5. As regards the algae, a high result (2,500 μμg Ra/gm ash) at Station 2 has been eliminated on the possibility that it had not been freed of attached silt and undissolved radium.

Radium in the algae apparently reached nearly 100 times the background or natural amount at Station 2 and then decreased progressively to Station 6, where it was about 5 times the natural radium content. The bottom insects reflect this picture in general, considering the more limited data available.

Strontium. Three algae samples (Stations 1, 3 and 6) from the third collection contained an average of 0.37 μμc of strontium-90 per gram of ash. A gamma scan indicated the definite presence of radium, ruthenium-103 and -106, and zirconium-95 and niobium-95. Two samples of bottom insects (Stations 1 and 6) had 0.37 μμc/gm ash of strontium-90, and one of them, from a gamma scan, contained ruthenium-103 and -106 as well as cesium-137. Numerical concentrations other than strontium 90 were not obtained.

Four of the fish samples analyzed for strontium-90 had an average of 1.4 μμc per gram of ash. A gamma scan of these samples indicated no significant gamma emitters to be present.

Milk Samples

Table XXXII indicates the results of analysis of the routine monthly milk samples collected at Farmington, N. M. from August, 1958, through March, 1959. Sample collection details have been indicated in Section III.

Table XXXII

Radioactivity of Milk

Collection Date	Gross Beta μμc per gram of ash	Radioactivity, μμc/liter				
		I^{131}	Sr^{90}	Sr^{89}	Ba^{140}	Cs^{137}
8/28/58	208	57	7.3	113	28	38
9/17	179	19	4.4	62	15	49
10/10	183	11	2.2	70	8	27
10/31	248	1,370	6.5	117	142	28
12/ 1	203	13	7.9	70	36	46
1/ 2/59	183	0	6.5	24	9	32
2/ 4	188	5	3.8	22	0	29
3/ 3	184	0	4.9	13	0	31
Mean	197		5.4			35

The special composite sample of pasteurized milk obtained from Farmington grocery stores from 11/10/58 through 12/10/58 contained 192 μμc of gross beta activity per gram of ash, and 25, 3.5, 26, 0 and 31 μμc per liter of I^{131}, Sr^{90}, Sr^{89}, Ba^{140} and Cs^{137} respectively.

One sample, that collected on 8/28/58, has been analyzed for radium, and contained 0.37 μμg of radium per liter.

The data of Table XXXII reflect the occurrence of nuclear weapons tests during 1958 as well as their absence thereafter. Except for the single high result for radioiodine, the milk supply for the Farmington area contained intermediate amounts of radioactivity as compared to other American cities.(20)

Precipitation

Table XXXIII presents gross alpha and beta radioactivity data for the rains that fell in the Durango - Farmington area from July 24 through September 13, 1958. Reference to Section II will provide data as to the quantity and scope of the individual rains. All samples were counted within two days after collection. Later counts, at one week and one month of age, are available for decay analysis, and will be discussed in a later report.

Selected rain samples were analyzed for specific radionuclides, and the results are shown in Table XXXIV. Samples of precipitation from Farmington for the period following the summer survey will be made available in a later report. It is of interest to note from Table XXXIV that at Farmington the Sr^{89} content of rain was 10 times the Sr^{90} content in all three cases.

Vegetable and Crop Samples

Table XXXV indicates the results of analysis of a variety of crops grown on farms of the Durango-Farmington area. All of the samples were collected in August and early September, 1958. Details of sample collection and handling have been noted in Sections III and IV. In general, the samples were washed and cleaned of topsoil in the laboratory and grains were husked.

The radium content of foods of the area ranged between 0.7 and 7.6 μμg per kilogram of live material in 33 samples, if alfalfa is excluded. The alfalfa contained 12.0 to 27.5 μμg of radium per live kilogram. The strontium-90 content of 28 samples ranged from 2.5 to 315 μμc per live kilogram, excluding the alfalfa and the single lettuce sample having 970 μμc/kg of Sr^{90}. Strontium-89 ranged from 0.0 to 1,740 μμc/kg live material, with the one lettuce sample having 13,400 μμc/kg.

Table XXXIII

Gross Radioactivity of Rainfall

Location and Date	Gross Radioactivity, μμc/l.*			
	Dissolved		Suspended	
	Alpha	Beta	Alpha	Beta
Durango, Colorado				
7/27/58	11	9,400	2	6,700
8/4	2	2,080	11	2,840
8/8	1	1,380	5	1,680
8/19	3	1,430	10	2,350
8/22	1	510	3	780
9/4	0	1,440	15	2,020
9/12	2	310	10	580
9/13	4	50	14	140
Farmington, New Mexico				
7/24/58	3	8,400	7	2,280
7/25	1	17,300	6	6,400
7/26	9	18,200	1	8,500
8/4	5	6,200	10	5,600
8/7	1	2,060	11	3,000
8/10	1	1,670	6	2,000
8/15	1	2,260	10	3,240
8/21	2	460	1	2,060
8/22	2	580	1	290
9/7	2	490	3	560
9/12	0	180	5	250

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* Counted within two days after collection.

As has been noted in Section I with regard to allowable concentrations of radioisotopes in food, the U. S. Atomic Energy Commission practice is to apply the same figures as are used for water, on a kilogram of live material basis. In this case, then, the allowable concentration of radium in foods would be 4.0 μμg per kilogram of live material, and for strontium-90 the allowable amount would be 80 μμc/kilogram live material. In viewing the data of Table XXXV in this light, however, it must be borne in mind that what is really desired is to minimize the quantity of

Table XXXIV

Strontium Content of Rains

Location and Date	Dissolved Activity, μμc/l.	
	Strontium-90	Strontium-89
Durango, Colorado		
8/8/58	5.3	-
8/22	0.7	29
9/12	5.2	-
9/13	1.8	-
Farmington, New Mexico		
8/10/58	7.1	76
8/21	3.1	33
9/7	6.7	-
9/12	23.0	230

any radioisotope taken in daily. Thus, for example, the concentration of radium in a particular food, say peanuts, may be quite a bit higher than 4.0 μμg/kg, but the quantity of peanuts eaten daily may be small. In that event the quantity of radium ingested daily via peanuts would be small. In the same sense, another individual might consume large quantities of peanuts, and in that case the daily radium intake would be significant.

The allowable concentrations noted above for radium and strontium-90 in food are useful as one index of whether these radioelements are present in significant amounts or not. These numbers are exceeded, at least slightly, in a number of the samples of Table XXXV. In order, therefore, to make a more precise interpretation of the significance of the data of Table XXXV, estimates of the average daily quantity of radium and of strontium-90 ingested are needed. These estimates have been made, and are presented in Section VIII of this report.

It should also be noted, in scanning the data of Table XXXV, that the highest radium concentrations occurred in alfalfa, a crop not consumed by humans, but generally used for cattle feed.

Table XXXV contains sufficient data for some comparison of the radium content of foods from farms located upstream and downstream from the Durango uranium mill. Excluding alfalfa, 11 kinds of sample (e.g., cabbage, green pepper, etc.) were collected at both upstream and downstream locations. Considering only those sets, the data indicate an average radium content of 2.0 μμg per kilogram of live material for farms upstream, against an average concentration of 3.6 μμg per kilogram for downstream farms irrigated with Animas River water. In other terms, the radium content of foods grown downstream is nearly double that of foods from farms north of the mill.

Further data on this subject are provided by the results of radium analysis of irrigation ditch water, as shown in Table XXXVI. The data for the downstream farms represent an average of either 2 or 3 results, whereas only a single analysis has been completed for the upstream farm. In that case, however, there is available in earlier tables considerable data as to the natural radium content of surface waters of the area. A value of about 0.4 μμg/1. would be a good estimate for the irrigation water upstream from the mill.

Topsoil samples for this area ranged from 1.4 to 2.8 μμg radium per gram of dry material, with an average for five results of 2.1 μμg/gm. These values are not significantly different from the natural radium content of the river muds.

Table XXXV

Radioactivity of Vegetables and Crops

Location and Type	μμc/kg Live Weight		
	Radium	Strontium -90	Strontium -89
Upstream Farms			
Cabbage	1.7	97	-
Lettuce	4.5	19	-
Green Pepper	2.2	-	-
Cucumber	1.0	-	-
Squash	1.3	4.9	-
Tomato	1.2	2.5	8.6
Sweet Corn	0.7	-	-
Sweet Corn	1.5	3.1	-
Potato	0.9	-	-
Potato	-	4.1	7.1
Wheat (husked)	7.2	4.8	88
Oats "	1.2	-	-
Pears	1.3	-	-
Apples	1.3	-	-
Alfalfa	13.0	62	705
Downstream Farms			
Cabbage	3.8	315	6.4
Cabbage	2.0	225	74
Cabbage	-	120	-
Lettuce	5.5	970	13,400
Green Pepper	4.8	-	-
Green Pepper	-	4.3	2.5
Cucumber	1.8	10	23
Squash	1.5	7.7	-
Squash	1.9	5.6	0.0
Squash	1.6	-	-
Tomato	-	10	2.0
Sweet Corn	-	2.6	0.0
Sweet Corn	-	18	1,470
Field Corn	2.4	-	-
Field Corn	3.4	-	-
Potato	-	5.4	-

Table XXXV (Cont'd)

Location and Type	μμc/kg Live Weight Radium	 Strontium -90	 Strontium -89
Carrot	3.9	12	-
Carrot	5.9	-	-
Beet	-	8.7	-
Onion	-	8.6	-
Okra	5.0	9.4	-
Peas	-	250	-
Green Beans	-	24	135
Wheat (Husked)	6.5	-	-
Oats (")	6.7	14	-
Pears	6.8	3.6	19
Apples	1.8	66	-
Apples	2.0	-	-
Peaches	5.8	-	-
Peaches	7.6	-	-
Peaches	-	5.9	-
Alfalfa	12.0	9.2	-
Alfalfa	27.4	-	-

Table XXXVI

Radium Content of Irrigation Water

Location	Radium μμg/l.
Upstream	
Farm A	0.0*
Downstream	
Farm B	5.0
" C	2.8
" D	4.7
" E	2.2

---

* Single result.

SECTION VII

STUDIES OF THE AQUATIC BIOTA

Introduction

Studies of the aquatic biota involved two major phases: (1) a study of the stream bottom was made in which bottom-dwelling insects and other organisms which could be collected by a screen were captured, enumerated, and identified for the purpose of determining the effects of wastes on these organisms; (2) bioassay tests were made of the mill effluents and major component wastes to determine their toxicity to the test fish, rainbow trout.

The study of organisms living on the Animas River bottom, both above and below the Vanadium Corporation of America mill at Durango, Colorado, and on two tributary streams, was conducted to compare the bottom populations at several locations below the mill with other populations not subjected to mill wastes. The tolerance of the various organisms normally inhabiting the stream bottom was evaluated by this method.

Toxic wastes will reduce the number of species and the total number of individuals which normally inhabit a stream. Bottom organisms are subjected to the total flow of the stream and respond to momentary maximum as well as long term average concentrations of toxic materials. The aquatic insects remain in the water from the time they hatch from eggs until they are ready to emerge as adults. This period of time will vary from a few days to a year or more.

Bioassay tests of industrial plant effluents and component wastes measure the toxicity of such wastes to test fish. The wastes, collected within the plant prior to discharge to the river, are diluted with appropriate amounts of river water, and the concentrations are determined which will kill one-half of the test fish in a specified period of time. These tests, conducted in the laboratory, simulate natural river conditions. They provide sufficiently accurate measures of the tolerance of fish to the wastes so that estimates can be made of the amount of river dilution water needed to prevent the wastes from harming the fish in the stream.

Both types of studies provide useful information. The release of sufficient quantities of toxic wastes can result in major fish kills. On the other hand, while lesser quantities of waste may not kill fish directly, they may destroy the bottom life on which fish depend for food, and thereby be equally destructive of fish populations. Many of the aquatic insects are more sensitive to toxic wastes than are fish. The reduction or elimination of aquatic organisms may be just as effective in eliminating fish from a reach of stream as the direct fish kills resulting from large toxic waste discharges.

Bottom Fauna Studies

A study of the bottom fauna in the Animas River and its tributaries, Lightner Creek and the Florida River, was undertaken during the summer and fall of 1958 to determine the effects of wastes discharged from the Vanadium Corporation mill at Durango, Colorado. The determination of the kinds of bottom organisms and the abundance of each kind was an important part of the evaluation of the effects of wastes discharged to the stream. A typical pattern existed in the Animas River in that a good variety and fairly large population of organisms were found at locations where the stream had not received toxic wastes. The study utilized stations along a 65 mile stream reach, and on two tributaries. These stations are shown in Table XXXVII. Figure 2 shows the general location of the stream reach studied.

Beginning in July 1958, aquatic insects and algae were collected from the river above and below the Vanadium Corporation of America mill for determination of gross radioactivity and radium concentration. These data are reported in Section VI. It was noted in July 1958, during the initial collection of bottom-dwelling organisms for radioactivity determinations, that there was a scarcity of organisms for a considerable distance downstream from the Vanadium Corporation of America mill. This scarcity was noted as far downstream as the Colorado-New Mexico State line, or for a distance of 28 miles below the Vanadium Corporation of America mill.

In September quantitative sampling was conducted at several locations on the river and on two tributary streams to obtain information relating bottom fauna populations with the wastes discharged from the uranium mill. Two environmental changes occurred during the summer which had a pronounced effect on the aquatic life. These were: (1) a gradual reduction of stream flow which resulted in less dilution of wastes

Table XXXVII

Sampling Stations for Bottom Fauna Collections-September 1958

Station No.	River Miles from Mill	Sampling Stations
1	-1*	Above Vanadium Corporation of America Mill at Fish Hatchery
1A	-0.2	Above Vanadium Corporation of America Mill. One-fifth mile above Highway 160 bridge.
1B	0.6; 0.1**	Lightner Creek. About 0.6 mile above junction with Animas River, and above mill tailings pond effluent.
1-CE	0.2	350 yards below main mill outfall on east side of river.
1-CM	0.2	350 yards below main mill outfall, middle of river.
1-CW	0.2	350 yards below main mill outfall on west side of river.
2	2.0	About two miles below mill.
3	0.2: 23.1**	Florida River. One-fifth mile above junction with Animas River.
4	23	Animas River at Highway 550 bridge, Colorado.
5	28	Animas River at Colorado-New Mexico State Line.
5A	36	Animas River at Highway 550 bridge in New Mexico. About 7.5 miles below State line.
5B	43	Animas River at Aztec near Indian ruins.
6	59	Animas River at Farmington, Highway 17 bridge.

---

*Minus values are upstream from mill.

**First figure refers to distance from junction with Animas River. Second figure refers to distance from mill.

received by the stream; (2) a mill process change in July 1958 which resulted in the release of very toxic wastes (see below, Bioassay Studies).

The flow characteristics of the stream for 1958 are shown in the daily hydrograph, Figure 3, Section II.

The aquatic insects, algae, and other organisms living on the river bottom are important sources of food for fish life. The reduction of this source of food by waste effluents will seriously limit the fish population in the affected stream reach. Data for September 1958 are included in Table XXXVIII which shows the numbers of organisms that were collected at each station, the number of species and the weight per unit area of stream bottom. Table XXXIX lists some of the organisms that were collected in July 1958. This list is significant because a comparison with the collections of September 1958 show that there was a reduction in the kinds of organisms in the stream during the period July to September.

Collection of Bottom Fauna. The Animas River and tributary stream beds are rocky and the flow is relatively swift in most places. Rocks vary in size and generally remain fairly well fixed on the stream bottom. Stable stream bed areas were selected for sampling of bottom fauna.

Of the sampling devices tried, the most successful was a copper wire screen which was one square yard in area and had fourteen wires per inch. The screen was supported at two opposite sides by wood strips, one by two inches by four feet. The screen was placed in the stream so that one edge of the screen rested on the bottom. The screen was then held in position with the wood strips so that water passed through the screen. A one square yard area immediately upstream from the screen was sampled by wiping the organisms from the rocks and stirring up the bottom. Detached organisms were carried in the current and deposited on the screen. The screen was lifted from the water and organisms removed with forceps and placed in marked vials. Later, organisms were identified, counted, and weighed.

The area of stream bottom sampled varied from one to several square yards. If organisms were numerous, one square yard was sufficient to indicate the relative abundance and the number of representative kinds. Several square yards were sampled where organisms were scarce.

Bottom organisms were collected generally at the same sampling stations from which water was collected for chemical and radioactivity analyses. Additional stations were selected to make more comparisons of biological productivity and to determine more precisely the inhibiting effects of the mill wastes. For example, samples of bottom organisms were collected just below the mill from the east side of the river, from the middle of the river, and attempts were made to collect from the west side of the river. In this area it was evident that the mill wastes flowed primarily along the west side of the river. Samples were collected at two stations below the State line, in addition to the one at Farmington,

Table XXXVIII

Number and Kinds of Organisms Collected from Stations

Organisms / Station	1	1A	1B	1-CE	1-CM	1-CW	2	3	4	5	5A	5B	6
Diptera - True fly													
Rhagionidae	20	36	12	22	3	-	5	5	35	89	36	5	-
Tendipedidae - Epoicocladius	7	22	-	1	1	-	-	2	-	-	-	-	1
Tendipedidae	-	-	-	-	-	-	-	-	2	2	5	-	-
Anthomyiidae - Limnophora	-	1	1	-	-	-	-	3	1	1	3	1	3
Simuliidae	-	-	5	-	-	-	-	20	-	-	-	-	-
Ephemeroptera - May fly													
Baetidae - Baetis spinosus	15	71	5	13	4	-	-	-	-	-	96	-	6
" (genera ?)	-	-	-	-	-	-	-	-	-	-	3	-	-
" Ephemerella sp. A	-	-	2	-	-	-	-	5	-	-	-	1	-
" " sp. B	-	-	-	-	-	-	-	8	-	-	-	3	-
Heptageniidae Heptagenia	-	-	-	-	-	-	-	6	-	-	-	-	-
Heptageniidae Rhithrogena	-	-	-	-	-	-	-	-	-	-	3	-	2
Ephemeridae (Oriathus ?)	-	-	-	-	-	-	-	-	-	-	5	-	27
Odonata - Dragon fly													
Gomphidae Ophiogomphus	1	-	-	-	-	-	-	7	-	-	1	-	1
Plecoptera - Stone fly													
Pteronarcidae Pteronarcella	21	5	3	12	1	-	-	-	-	2	5	2	2
Perlodidae Isogeninae	12	2	7	-	-	-	-	14	-	-	11	35	46
Pteronarcidae Pteronarcys	-	-	-	-	-	-	-	2	-	-	-	-	-
Trichoptera - Caddis fly													
Hydropsychidae Hydropsyche	409	81	41	24	1	-	-	501	-	-	2	374	268
Leptoceridae Leptocella(Albida?)	416	206	1	157	-	-	-	-	-	-	-	1	4

(continued)

Table XXXVIII (continued)

Number and Kinds of Organisms Collected from Stations

Station	1	1A	1B	1-CE	1-CM	1-CW	2	3	4	5	5A	5B	6
Organisms (continued)													
Coleoptera - Beetle													
Haliplidae	1	-	-	-	-	-	-	-	-	-	-	-	-
Helodidae	-	-	3	-	-	-	-	-	-	-	3	-	-
Annelida - Worm	-	1	-	1	3	-	-	-	1	-	-	-	-
Hemiptera - True bug													
Naucoridae	-	-	-	-	-	-	-	16	-	-	1	-	-
Veliidae	-	-	-	-	-	-	-	-	-	-	-	1	-
Lepidoptera - Moth													
Pyralididae Elophila	-	-	-	-	-	-	-	1	-	-	-	-	-
Mollusca - Snail	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocarina - Water mites	-	-	-	-	-	-	-	-	-	-	12	-	-
TOTAL NUMBER	903	425	80	232	13	0	5	590	39	95	185	423	360
Number of species	9	9	10	7	6	0	1	13	4	5	14	9	10
Square Yards sampled	2	1	1	2	1	-	3	3	6	7	3	1	2
Number per square yard	451	425	80	116	13	0	2	197	6.5	14	62	423	180
Weight of Organisms (Gms.)	16.3	9.6	2.2	4.3	0.2	0	0.2	6.5	1.5	1.0	1.5	6.4	3.8
Weight of Organisms per square yard	8.1	9.6	2.2	2.1	0.2	0	0.07	2.2	0.25	0.14	0.5	6.4	1.9

Table XXXIX

A List of Some of the Organisms Present at the Stations in July 1958

	Common Name	Family	Genus
Station 1	Stone fly	Perlodidae	Isogeninae
	Caddis fly	Hydropsychidae	Hydropsyche
	May fly	Baetidae	Ephemerella
Station 2	Caddis fly	Hydropsychidae	Hydropsyche
	True fly (Snipe)	Rhagionidae	
	May fly	Baetidae	Ephemerella
Station 3	May fly	Heptageniidae	Heptagenia
	Caddis fly	Hydropsychidae	Hydropsyche
Station 4	True fly (Snipe)	Rhagionidae	
	May fly	Baetidae	Ephemerella
Station 5	May fly	Baetidae	Ephemerella
	Caddis fly	Hyrdopsychidae	Hydropsyche
Station 6	True fly	Tendipedidae	
	Caddis fly	Hydropsychidae	Hydropsyche

to determine more precisely the stream reach in which certain organisms reappeared.

Results. Populations of bottom fauna were similar in the Animas River, Florida River, and Lightner Creek where these streams were not affected by wastes. A comparison of the data in Table XXXVIII shows reasonable similarity in the numbers of bottom organisms and the representative kinds in the unpolluted waters.

The mill effluents which are discharged to Lightner Creek and the Animas River flow along the west side of the river for some distance before becoming mixed across the river. Stations 1-CE, 1-CM, and 1-CW were located in the east, middle and west parts of the stream, respectively, about 350 yards below the mill. It was obvious from visual observation that most of the wastes flowed along the west bank of the river, where no organisms could be found. The data show that bottom organisms were also adversely affected in the middle of the river though discoloration from wastes was not apparent. A nearly normal population of bottom fauna was found on the east side, indicating that the mill wastes had not reached this area. In addition to the one square yard sample from the middle of the river, several rocks were examined to confirm the finding of a scarce population. Several dead fish (suckers) were in the river lodged against rocks or debris.

Station 2 was located about two miles downstream from the mill, where the wastes were mixed well with the stream. In September, the stream bottom was covered with algae and much of it gradually sloughed off and was carried downstream. The prolific growth of algae was not present in July though there was evidence in slower waters that a heavy growth had occurred earlier. In September, many rocks were examined without finding any trace of attached insect life. In a three square yard sample only five fly larvae were recovered. Table XXXIX which lists some of the organisms obtained in July shows that caddis flies and may flies were found at this station at that time, in addition to the true flies. It is evident from this comparison that environmental conditions were more unfavorable to insect life in September than in July.

At Station 4, which was 23 miles below the mill, the appearance of the stream was normal, being clear and without excessive growth of algae. However, a sampling of six square yards of bottom yielded only 38 fly larvae and one worm, or 6.5 organisms per square yard. This is poor production of bottom fauna when compared to the 180 to 451 organisms per square yard in areas not affected by wastes.

The scarcity of bottom organisms existed at the State line (Station 5), 28 miles below the mill, where only 14 insect larvae per square yard were collected in a seven square yard sample.

An increase in the number of organisms was noted at Station 5-A, located 36 miles below the mill. Insect larvae other than flies appeared at this station, and total insects numbered 62 per square yard.

Forty-three miles below the mill the number, kinds, and weight of bottom fauna collected were nearly equal to the collections made above the mill. The number of bottom fauna exceeded somewhat those collections made at Farmington and on the tributary streams.

The station at Farmington was the farthest downstream station, being 59 miles below the mill. A fairly sizeable population of 180 organisms per square yard was collected there.

Figure 14 is a graphic presentation of the bottom fauna collection data. A general pattern which shows a sharp reduction of organisms just below the mill outfalls is evident. The graphs show that the river is adversely affected past the State line. Recovery of the stream is first indicated 36 miles below the mill, where a larger variety of organisms was found, but where the number and weight of the organisms were much less than at stations above the source of pollution.

Organisms least tolerant of pollution were caddis flies, may flies, and stone flies. These were absent in the stream from the mill to the State line with the exception of two stone flies found at the State line.

The true flies (Rhagionidae) were most tolerant of pollution. They were by far the most predominant organisms found at Stations 2, 4, and 5 and represented the greatest portion of the weight collected at Station 5-A.

In July 1958, it was noted that organisms were not numerous at Stations 2, 4, and 5. It was observed, however, that the sensitive may flies, caddis flies, or stone flies were present. In July there was no attempt to make qualitative or quantitative determinations of bottom fauna populations, since the main objective at that time was only to obtain a sufficient quantity for radioactivity analyses.

Figures 15 through 26 are photographs of the collection of bottom organisms found at each station. In each case the entire sample is shown, with information as to the number of square yards from which it was obtained. No photograph is shown for Station 1-CW because no organisms were found there.

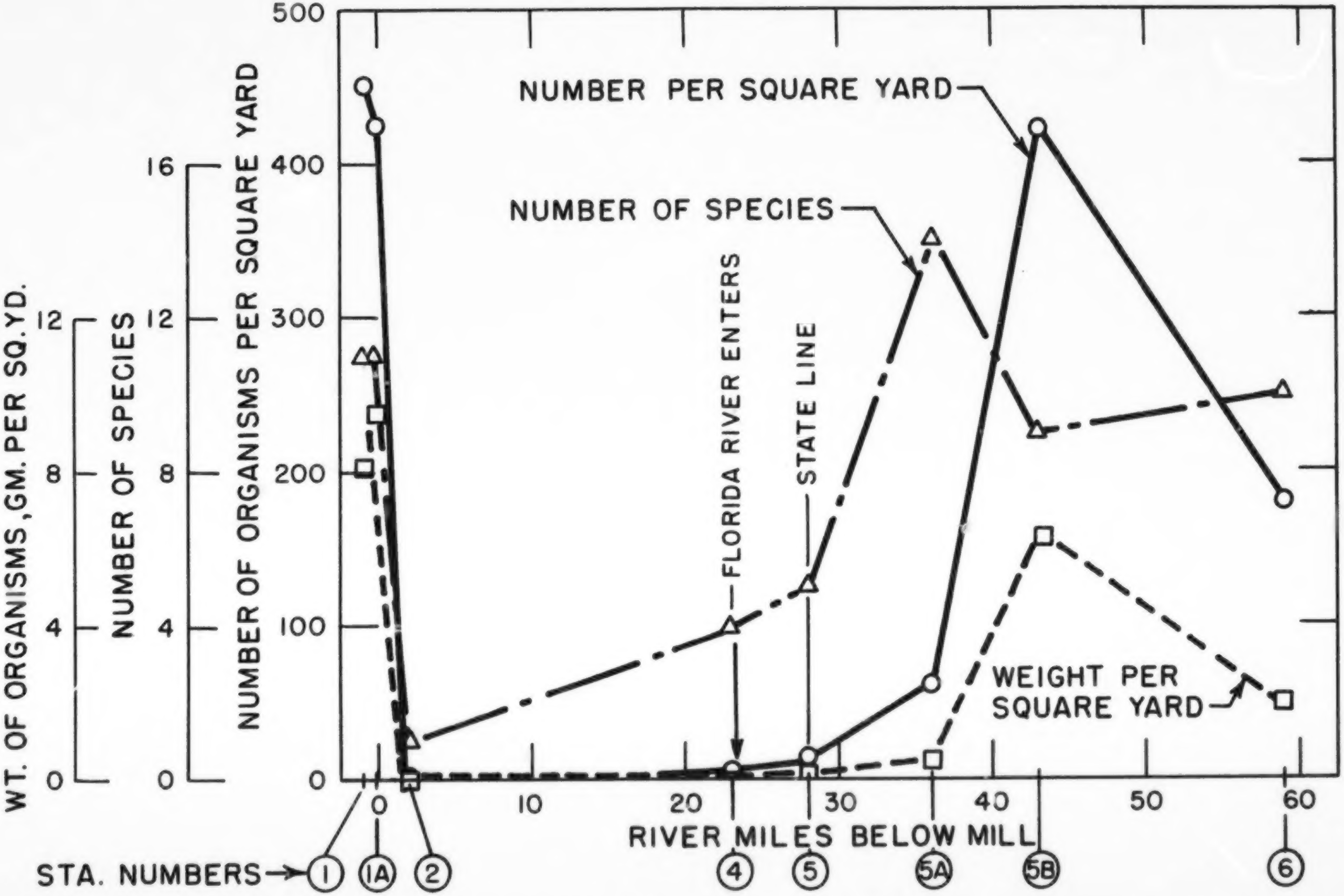
Some algae were collected from the river during July and again in September. A list showing some of the kinds of algae present is given in Table XL. Above the mill the mass *Fontinalis* was predominant. Below the mill *Stigeoclonium* was commonly found, and blue-green algae were very abundant at Station 2 in September. The growth of algae appeared to be influenced most by temperature. Luxuriant growth developed as the water temperature became higher. In Lightner Creek below the tailings pond discharge the blue-green alga *Oscillatoria* grew well. Within the filaments of *Oscillatoria* there were great numbers of the diatoms *Cyclotella*, *Frogellaria*, *Navicula*, *Synedra*, and *Tabellaria* and the desmid *Cosmarium*.

Bioassay Studies

The Vanadium Corporation of America mill located at Durango, Colorado, produces uranium and vanadium, and discharges wastes to Lightner Creek and the Animas River through three separate outfalls. Bioassay studies were undertaken to determine the toxicity of the wastes to rainbow trout, the most important game fish in the stream.

The two wastes to the river are referred to as main effluent and tailings pond effluent. Since the main effluent consists of several specific process wastes (primary tailings, organic raffinate, and vanadium filter tray wash) each of these components also were tested for toxicity to fish.

The bioassay studies were performed in accordance with generally accepted procedures.(21) These procedures required the exposure of test



BOTTOM FAUNA STUDIES

FIGURE 14

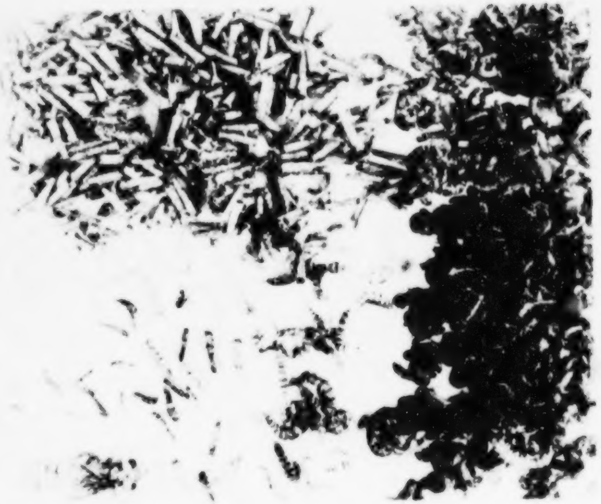


FIGURE 15
BOTTOM INSECTS, STATION 1
1 SQ. YD.

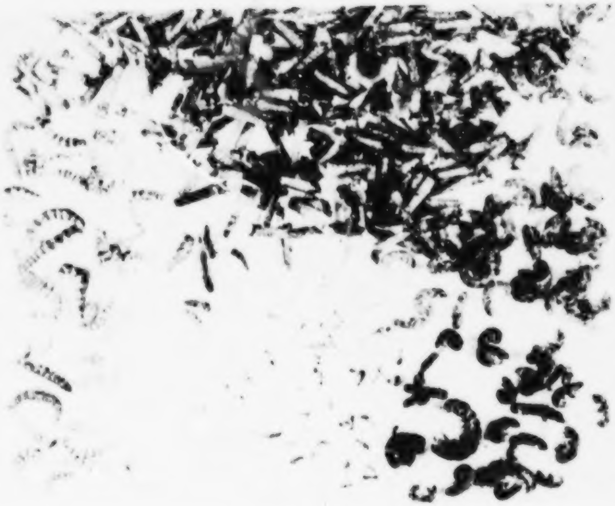


FIGURE 16
BOTTOM INSECTS, STATION 1A
1 SQ. YD.

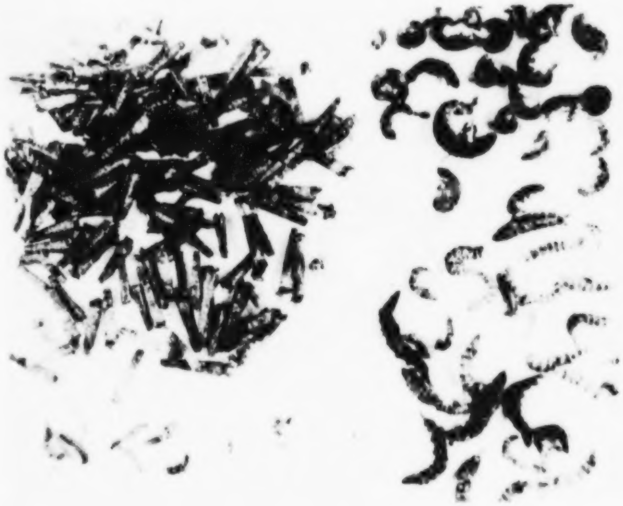


FIGURE 17
BOTTOM INSECTS, STATION 1CE
2 SQ. YD.

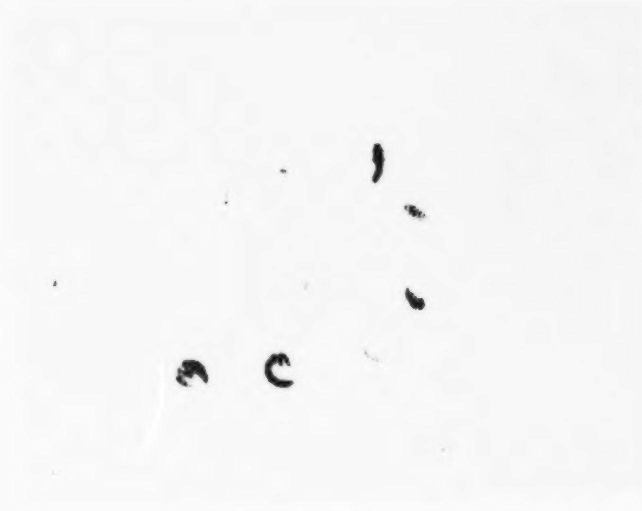


FIGURE 18
BOTTOM INSECTS, STATION 1CM
1 SQ. YD.

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FIGURE 19
BOTTOM INSECTS, STATION 2
3 SQ. YD.

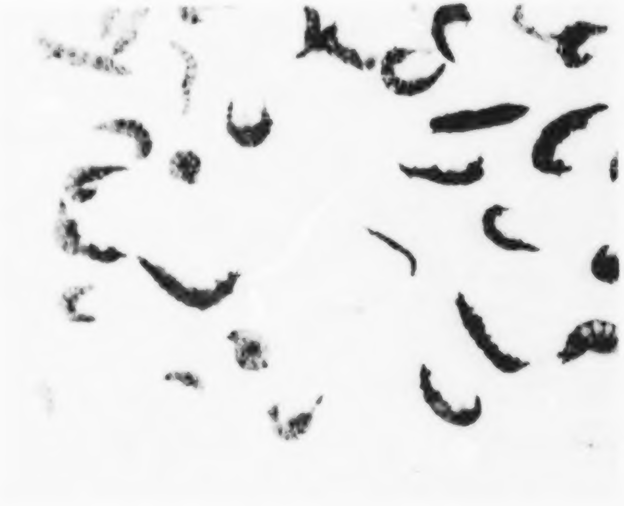

FIGURE 20
BOTTOM INSECTS, STATION 4
6 SQ. YD.

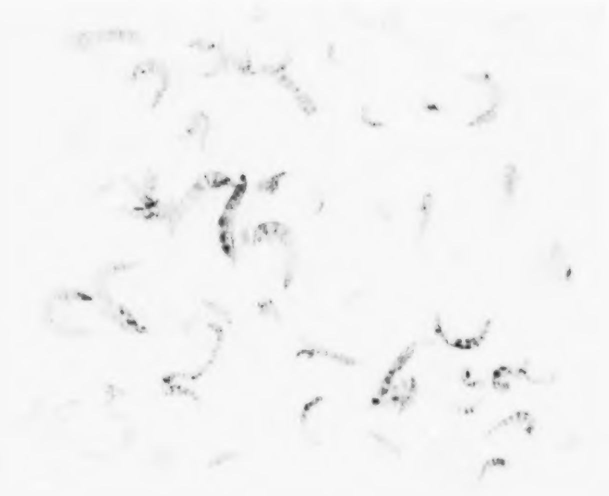

FIGURE 21
BOTTOM INSECTS, STATION 5
7 SQ. YD.

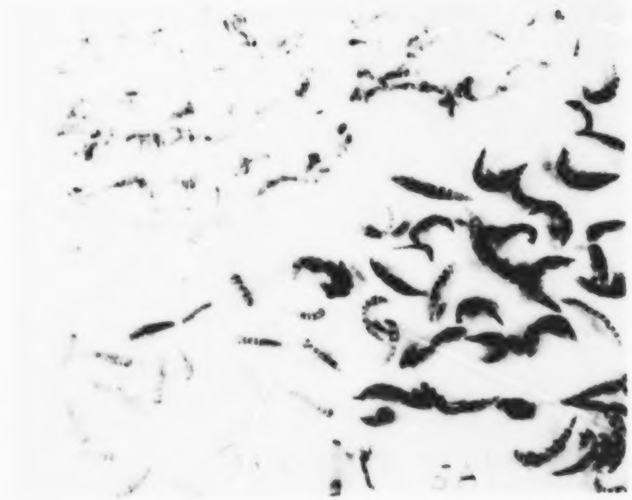

FIGURE 22
BOTTOM INSECTS, STATION 5A
3 SQ. YD.

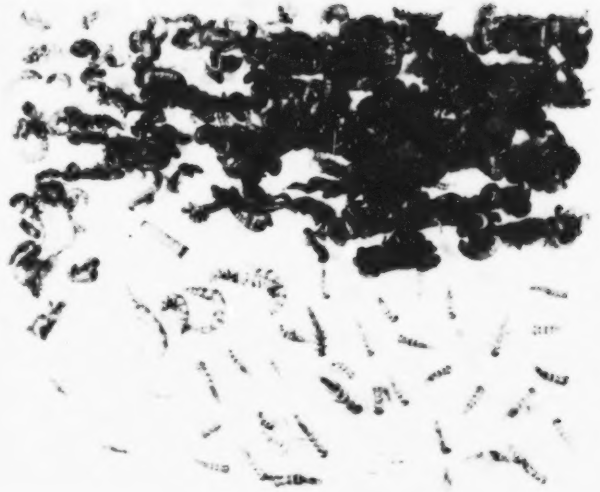

FIGURE 23
BOTTOM INSECTS, STATION 5B
1 SQ. YD.

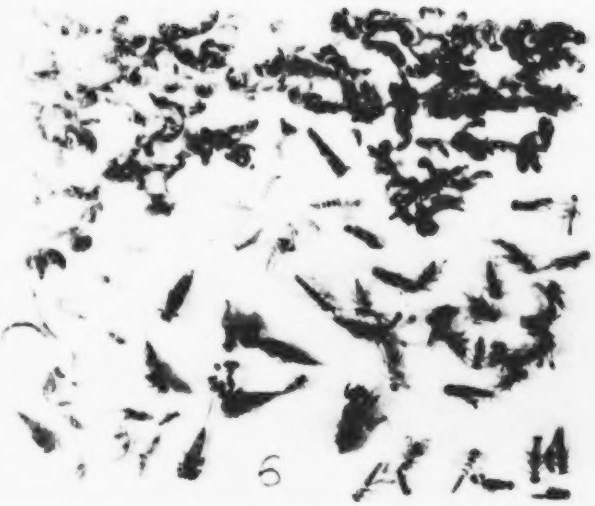

FIGURE 24
BOTTOM INSECTS, STATION 6
2 SQ. YD.

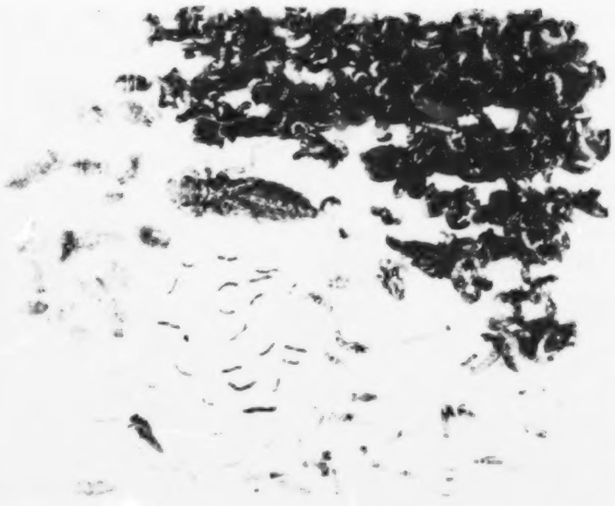

FIGURE 25
BOTTOM INSECTS, STATION 3
(FLORIDA RIVER)
3 SQ. YD.

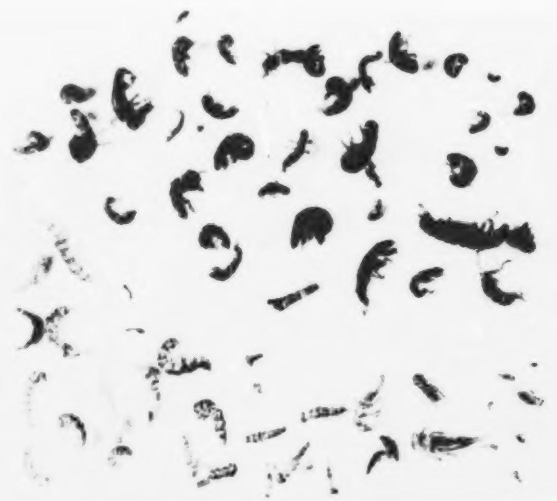

FIGURE 26
BOTTOM INSECTS, STATION 1B
(LIGHTNER CREEK)
1 SQ. YD.

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Table XL

Partial List of Moss and Algae from River

July	September
Station 1	
Moss - Fontinalis	Fontinalis
Station 2	Stigeoclonium
	Blue-green
Station 3	
Alga - Stigeoclonium	Spirogyra
Station 4	
Alga - Stigeoclonium	Stigeoclonium
Station 5	
Alga - Stigeoclonium	Stigeoclonium
Station 6	
Alga - Cladophora	Spirogyra
Diatoms	Fungus - mold

fish to various concentrations of wastes diluted with the receiving river water. By observing the mortalities which occurred in the several test solutions, it was possible to interpret the data to obtain the concentrations of wastes in which 50% of the fish would survive in a specified period of time (24, 48, 72 hours or longer). The per cent of waste in which there is 50% survival is known as the Median Tolerance Limit (TL_m).

The information obtained concerning the acute toxicity of the effluents to fish life is valuable in estimating dilution requirements to prevent periodic fish kills. Of greater importance, however, is the need to properly estimate dilution water required to prevent long term detrimental effects to fish and other forms of life, especially bottom dwelling insects, upon which the fish are dependent for food. An application factor can be developed for the purpose of applying information obtained from short term bioassay studies to dilution water requirements in the stream. The TL_m value is used as a basis for determining such an application factor. Since the TL_m value gives the concentration at which 50% of the fish survive under short time exposure, a lower concentration is needed to insure 100% survival for an indefinite period. Other factors which need to be considered in determination of an application factor are sensitivity of the fish or fish food organisms to be protected, variability of the toxic wastes, and the influence of physical factors such as temperature and pH. Chemical characteristics of the river water which increase or decrease toxic characteristics of the wastes must also be considered. The Aquatic Life Advisory Committee(22) states: "It is believed that the result of the 48-hour TL_m multiplied by an application factor of 0.1 represents a concentration of waste which usually will not produce adverse effects on the aquatic organisms as a whole." Developing a realistic application factor for the wastes under study is a difficult problem because of the complexity of the wastes, which contain organic compounds and several metallic elements known to be toxic in small concentrations over long exposure periods. It is difficult to predict with precision the long term exposure effect of such wastes to fish or other aquatic life.

Bioassay Methods. The Colorado Game and Fish Department provided space in one of the hatchery buildings in Durango for the tests. Spring water at a temperature of 52° F. flows into the hatchery troughs. Test containers were placed in these troughs where a water depth of approximately five inches was maintained. This provided a constant temperature of 52° F. for the test solutions. Test containers consisted of one gallon jars, 10 quart porcelain pails, and five gallon wide-mouth glass jars. Composite and instantaneous samples of the mill wastes were collected for the bioassay studies.

Test solutions were made by diluting the various mill waste samples with Animas River water which had a pH range of 7.2 to 7.5, alkalinity of 110 to 132 mg/L and hardness of 210 to 230 mg/L. The river water was collected at Station 1 which is near the State Fish Hatchery and about a mile upstream from the Vanadium Corporation of America mill. The river was also sampled for chemical, biological, and radioactivity analyses at Station 1.

Test fish were obtained from the Durango hatchery rearing ponds and were held until used in the hatchery troughs adjacent to the test containers. Feeding was on a limited basis and no food was supplied during the test period. Fish 1-1/4 to 2-1/2 inches in length were used for the tests. Records were kept of the exposure time and the number of fish which died in the various test solutions. Data obtained were used to plot survival versus concentration of waste to obtain median tolerance limit values.

Chemical data were obtained for representative test solutions at the beginning of tests and at their conclusion. These analyses consisted of dissolved oxygen, pH, alkalinity, acidity and hardness. Dissolved oxygen determinations also were made during the course of the tests if there was a reason to suspect that low dissolved concentrations were causing fish to become distressed. Oxygen concentrations were maintained at an adequate level by limiting the number of fish in the test containers. Oxygen was supplied solely through surface absorption.

Control fish were kept under identical conditions with each test series or group of tests. No mortalities occurred among control fish.

Fish that died in the toxic waste solutions were removed as soon as possible after death to prevent bacterial growth and excessive utilization of oxygen.

It was not possible to store a single collection of dilution water for all the tests. River water was collected in several ten gallon tin-lined milk cans as required. Small, though variable chemical characteristics of the dilution water resulted in slight differences in the test solutions made with the same waste sample. These differences had no significant effect on the results.

Insofar as possible, tests were run using ten fish for each concentration in the test series. In several instances, five fish were used and in a few cases only two fish were used in each test container. The containers with two fish were usually used in preliminary tests to establish the toxic range of the waste.

Composite and grab samples of mill wastes were tested for toxicity. Small volumes (about 1 liter) of samples from final tailings, vanadium filter wash, and organic raffinate were available from the mill survey conducted August 3 to 5, 1958. These composite samples were collected, as has been described in Section V, over a 56-hour span. The five-day composite samples for the main effluent and final tailings effluent were collected daily for a five-day period, August 12 to 16, 1958. The eight-hour composite samples for each of the five types of waste were collected hourly for a consecutive eight-hour period on August 19, 1958. The individual samples collected on this date were used for the grab sample tests.

Results. The effluents discharged to the river were acid. The pH of the effluents and the resultant pH values when these wastes were mixed with various amounts of river water are shown in Table XLI. The Table shows that, of the two effluents, the tailings effluent was more acid. Ninety per cent river water mixed with 10% main effluent resulted in a pH of 6.4 while 90% river water and 10% tailings effluent resulted in a pH of only 2.6. Low pH wastes would be detrimental to aquatic life if wastes were discharged in such quantities that adequate dilution would not be afforded. However, the tests showed that chemical toxicity occurred in solutions which were too dilute to be greatly affected by depressed pH values.

Variations in toxic concentrations of the main effluent and the main effluent component wastes were considerable. The color of the main effluent ranged from a bright yellow to pale gray. A grab sample of the yellow-colored effluent had a 72-hour median tolerance limit of 0.31% while a pale gray-colored grab sample had a 72-hour median tolerance limit of 7.6% or a difference in toxicity of about 25 times. The two composite samples of main effluent had 96-hour median tolerance limits of 0.44% and

1.5%. The effect of adding main plant effluent to the dilution water was generally to moderately lower pH and alkalinity. Acidity and hardness values increased a moderate amount. One grab sample had a slight but opposite effect on chemical characteristics than the other samples.

The primary tails overflow, a component of the main effluent, had the least toxicity of any of the five wastes tested. The 72-hour median tolerance limits of two composite samples ranged from 13% to 18%. The addition of primary tails overflow water to the dilution water caused an increase of pH and alkalinity and a moderate reduction in hardness.

Samples of vanadium filter tray wash water had 96-hour median tolerance limit values ranging from 1.0% to 4.2%. The addition of vanadium filter tray wash water to the dilution water caused a moderate reduction of pH and an appreciable reduction of alkalinity in the greater waste concentrations. Hardness was reduced only slightly.

Organic raffinate was the most toxic waste tested. The 72-hour median tolerance limit values ranged from 0.09% to 0.21%. This component is important because it has an appreciable effect on the toxicity of the main effluent. The addition of organic raffinate to dilution water reduced pH values and alkalinity moderately in the low concentrations (0.1 to 0.18%) but a 1% concentration reduced pH to 4.0 and increased acidity and hardness values greatly. Fish were killed in low concentration test solutions where there were only moderate changes in chemical characteristics.

The final tailings effluent which is discharged to Lightner Creek and directly to the river had 96-hour TL_m values ranging from 1.3% to 3.3%. Three different composite samples were tested. Although the effect on resultant chemical characteristics was variable when this waste was mixed with dilution water, there always was a reduction of pH and alkalinity and an increase in hardness. Solutions containing 3.2% of this waste varied in pH from 4.1 to 6.9. Toxicity was exhibited on test solutions with pH values ranging as high as 6.0 and 7.0.

Summary. A summary of bioassay TL_m determinations, the volumes of waste flows and the calculated volumes of dilution water required for each waste to be diluted to the TL_m concentrations are presented in Table XLII. This Table shows considerable variation in the toxicity of different samples of the same waste as well as variation among the five wastes.

Differences in the wastes also can be detected visually. The main effluent appeared yellow in most samples but also was milky or pale gray at times. The vanadium filter tray wash varied from clear to red and the organic raffinate varied from yellow to pale green.

Flow records for the stream gage station at Durango show that for the period 1935-1956 minimum daily average flows ranged from 110 to 212 cfs, with an average for the period of record of 145 cfs. A comparison

Table XLI

pH Changes of River Water on Adding Effluent

Main Effluent

		pH
100%	Effluent	4.7
10%	Effluent and 90% River Water	6.4
3.2%	Effluent and 96.8% River Water	6.7
1%	Effluent and 99% River Water	7.2
100%	River Water	7.9

Tailings Effluent

			pH
100%	Effluent	less than	2.0
10%	Effluent and 90% River Water		2.6
3.2%	Effluent and 96.8% River Water		4.8
1.0%	Effluent and 99% River Water		6.5
100%	River Water		7.9

with the dilution volumes required to produce TL_m concentrations for the wastes tested show that the main effluent sometimes can be expected to cause severe fish mortality. The organic raffinate component of the main effluent was the most toxic. Reduction or elimination of this waste would materially reduce toxicity of the main effluent.

Dilution volumes of river water required to render the indicated volumes of wastes equivalent to TL_m concentrations were calculated by applying the formula:(23)

$$\frac{100 - TL_m}{TL_m} \times \text{waste flow} = \text{Dilution Volume}$$

Table XLII

River Dilution Requirements for TL_m Concentrations

Based on Mill Wastes Flows

	Wastes Flows		TL_m (Median Tolerance Limit in per cent)				No. Fish per Test	Dilution Volume (cfs)for 96 or 72 Hr. TL_m
Main effluent *	gpm	cfs	24 Hr.	48 Hr.	72 Hr.	96 Hr.		
8/12-16 5 day comp.	270	.601	3.3	1.8	1.5	1.5	5	39
8/19 8 hr. comp.	270	.601	>.56	.56	.44	.44	10	136
8/19 #8 grab (yellow)	270	.601	0.8	.42	.31	-	5	193
8/19 #5 grab (gray)	270	.601	-	-	7.6	-	5	7
Vanadium Filter Wash								
8/3-5 56 hr. comp.	52	.115	8.2	4.2	4.2	-	2	2.6
8/19 8 hr. comp.	52	.115	4.6	1.4	0.82	0.82	10	14
8/19 #3 grab (clear)	52	.115	>5.6	5.6	1.8	1.0	10	11
8/19 #8 grab (red floc)	52	.115	>1.8	>1.8	1.8	1.8	10	6
Organic Raffinate								
8/3-5 56 hr. comp.	32	.071	0.1	0.1	0.1	-	2	71
8/19 8 hr. comp.	32	.071	>.18	0.1	0.09	.09	10	79
8/19 #2 grab (yellow)	32	.071	>.18	0.1	-	-	5	71
8/19 #4 grab (pale green)	32	.071	0.62	0.28	0.21	-	5	34
Primary Tails Overflow								
8/3-5 56 hr. comp.	85	.190	>18	>18	>18	-	2	<1
8/19 8 hr. comp.	85	.190	16	14	13	-	5	<1

(continued)

Table XLII (Continued)

River Dilution Requirements for TL_m Concentrations

Based on Mill Wastes Flows

	Wastes Flows		TL_m (Median Tolerance Limit in per cent)				No. Fish per Test	Dilution Volume (cfs) for 96 or 72 Hr. TL_m
	gpm	cfs	24 Hr.	48 Hr.	72 Hr.	96 Hr.		
Tailings Effluent								
8/12-16 5 day comp.	93	.207	1.3	1.3	1.3	1.3	5	16
8/3-5 56 hr. comp.	93	.207	1.8	1.8	1.8	1.8	2	11
9/19 8 hr. comp.	93	.207	4.1	3.9	3.7	3.3	5 to 10	6

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* Main effluent composed of Vanadium filter wash, organic raffinate, primary tails overflow, fresh water, and iron-aluminum sludge.

Waste flow characteristics are shown in Figure 27. To protect fish and the aquatic bottom fauna which are less tolerant of toxic wastes, an application factor varying from one-third to one-tenth of the TL_m concentration must be applied to determine dilution requirements. Thus, if an application factor of one-third is used a conservative estimate of the required dilution results. Use of an application factor of one-tenth would require greater dilution volumes.

Using the minimum application factor of one-third with the 72-hour TL_m's and the waste flows indicated in Table XLII, it is estimated that the uranium mill main effluent may require as much as 580 cfs of dilution water in order to avoid harm to the fish and other aquatic organisms, while the tailings pond effluent may require as much as 50 cfs. These values are based on the observed maximum dilution volumes for 50 per cent survival in each case. Hence a total flow in the Animas River of over 600 cfs may be required at times to protect the aquatic life. As has been seen, the flow in the river is well below this level for much of any year (Section II). In the summer of 1958 flows dropped to about half of this level, with resulting observed sharp reductions of bottom organism species and populations. Again, it appears from the data that irrigation practice in the area aided the stream in its recovery in New Mexico, in that the concentrations of toxic materials was reduced below the State line in much the same fashion as has been indicated for dissolved radium.

Summary and Conclusions

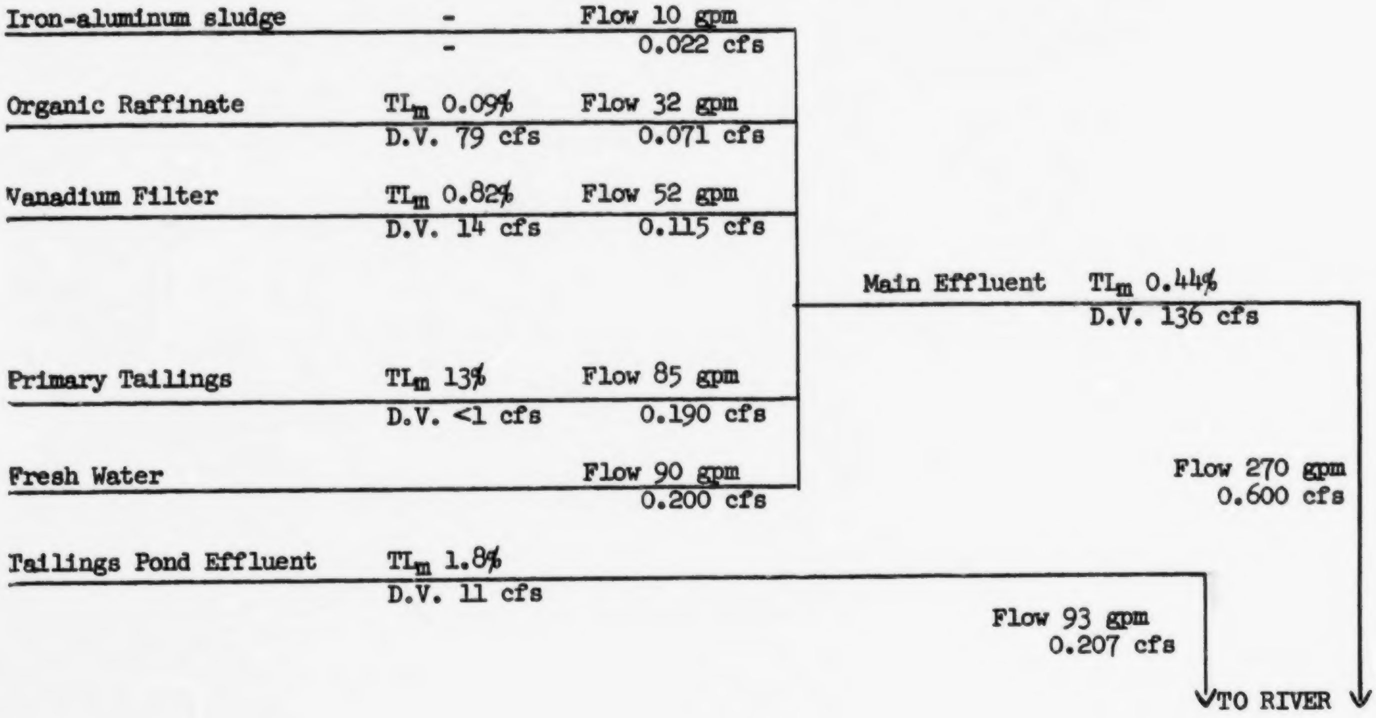
Thirteen stations on the Animas River and tributaries were sampled in September 1958 to obtain bottom fauna for enumeration of kinds and numbers of organisms present. A tabulation of the organisms collected has been presented, and photographs are included of the organisms collected at each station (Figures 15 through 26).

The Animas River, above the Vanadium Corporation of America mill and at a distance approximately 45 miles below the mill, and the tributaries, Lightner Creek and Florida River, were productive streams having a fairly large number and variety of aquatic insects. Because of the chemical toxicity of wastes discharged from the Vanadium Corporation of America mill, all bottom fauna were eliminated near the mill effluent and were greatly reduced in number as far downstream as the State line. Normal bottom fauna populations reappeared in New Mexico, about 16 miles below the State line.

Observations of bottom fauna made in July 1958 indicated that less tolerant insects, such as may flies, caddis flies, and stone flies, were present, though not in great numbers. The later elimination of these insects in the reach of the river from the mill to the State line was probably due to the lower river flow affording less dilution of the wastes, and the greater toxicity of new process wastes, especially the organic raffinate.

Figure 27

Schematic Diagram Showing
Waste Components, Effluents, Toxicity,* and Dilution Volumes


Iron-aluminum sludge
-
-
Flow 10 gpm
0.022 cfs
Organic Raffinate
TL_m 0.09%
D.V. 79 cfs
Flow 32 gpm
0.071 cfs
Vanadium Filter
TL_m 0.82%
D.V. 14 cfs
Flow 52 gpm
0.115 cfs
Main Effluent
TL_m 0.44%
D.V. 136 cfs
Primary Tailings
TL_m 13%
D.V. <1 cfs
Flow 85 gpm
0.190 cfs
Fresh Water
Flow 90 gpm
0.200 cfs
Flow 270 gpm
0.600 cfs
Tailings Pond Effluent
TL_m 1.8%
D.V. 11 cfs
Flow 93 gpm
0.207 cfs
TO RIVER

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* Toxicity (96 hr. TL_m) based upon 8 hour composite samples.

Two major wastes are discharged from the Vanadium Corporation of America mill to the Animas River and Lightner Creek. These wastes are the main effluent, and the final tailings waste. Several process wastes combine to form the main effluent. In all, five wastes were tested for toxicity to rainbow trout. River water, into which the wastes are discharged, was used to dilute the mill wastes samples. A series of different strengths of wastes was prepared for each waste and the survival of fish in the test solutions observed. Composite and grab samples as practicable were used for the toxicity tests. Considerable variation in toxicity was found.

The least toxic waste tested was the primary tails overflow, a component of the main effluent. The most toxic waste was organic raffinate, another component of the main effluent. The following toxicities (72 or 96-hour TL_m) of the five types of wastes tested are arranged in increasing order of toxicity together with volumes of river water required to dilute measured flows of mill waste types to the TL_m concentrations (at which 50 per cent survival occurred).

		TL_m Range	Dilution Volume (cfs)
(a)	Primary tails overflow	13 to 18%	< 1
(b)	Final tailings effluent	1.3 to 3.3%	6 - 16
(c)	Vanadium filter tray wash	0.82 to 4.2%	2.6 - 14
(d)	Main effluent	0.31 to 7.6%	7 - 193
(e)	Organic raffinate	0.09 to 0.21%	34 - 79

Using a conservative application factor of one-third, it appears from these results that Animas River flows of 600 cfs at Durango would be required to provide sufficient waste dilution to protect the aquatic life of the stream. River flows drop well below this level for a large part of every year. They did so specifically in the summer of 1958, at which time the bottom organism populations below the mill were greatly reduced, thus nearly eliminating the basic food required by fish.

SECTION VIII

ESTIMATES OF HUMAN INTERNAL RADIATION EXPOSURE

As has been indicated, the total quantity of any radioisotope ingested daily, rather than its concentration in any medium such as water or food, is the desired measure of internal radiation exposure. Much of the data reported in previous sections of this report can be interpreted in terms of the quantities of radium and strontium ingested daily by people of the Durango-Farmington area, and that is the purpose of this Section. The amount of external radiation exposure for the area, while most probably negligible compared to these results, has not been measured and is not included here.

As the means of interpretation in terms of existing recommended standards,(8)(9)(10) the permissible daily intakes of radium, and of strontium-90 have been computed on the basis of their MPC's in water. Thus, radium has an allowable concentration of 4 μμg/l and that for strontium-90 is 80 μμc/l, as outlined in Section I. Handbook 52(8) indicates that these concentrations are based upon an average consumption of water of 2.2 liters per person per day. Hence it has been calculated that the allowable daily intakes of radium and of strontium-90, via any path (water, food, air, etc.) are 8.8 μμg and 176 μμc per person per day, respectively. The observed radium and strontium-90 levels in the various kinds of medium are interpreted in terms of these figures.

Water

Radium. From the data of Section VI, the average treated water concentrations of radium at Aztec and Farmington, New Mexico, observed during the summer of 1958, were 3.6 and 2.6 μμg/l, respectively. Based upon an average daily intake of 2.2 liters, it follows that the average daily radium intake of people using these treated water supplies was 7.9 and 5.7 μμg per day of radium at Aztec and Farmington, respectively. This amounts to 90 and 65 percent, respectively, of the allowable daily intake, at that time. In order to interpret these figures on an annual average basis, it is necessary to consider other seasons in which irrigation is not practiced, and other river flows. This will be considered below.

The data indicate that the water treatment plants at Aztec and Farmington do not remove dissolved radium from the raw water. The likelihood is also indicated that whenever the filter units at these plants become contaminated with radium-bearing solids, some of this radium may dissolve out into the treated water supply.

Raw water users in New Mexico were exposed to average radium concentrations of as much as 7.6 μμg/l in the area between the State line and Aztec. (See Section VI, Table XVII, Station 5). This resulted in a daily intake of radium for these people of 16.7 μμg during the survey period, or nearly two times the allowable amount of 8.8 μμg/day.

As has been indicated earlier in Section VI, it is probable that local irrigation practice protected the Aztec and Farmington water supplies during the warmer months by, in effect, reducing the radium concentration in the river water before it reached these locations. An extended low flow period also occurs usually in the winter months, and it is dubious that the same effect occurs then. In other terms, it appears probable that during this winter period people of Aztec and Farmington are exposed to higher radium concentrations in their treated water supply, more nearly those concentrations that occur at the State line, on the same river flow basis. The daily intake of radium from the treated water supplies would then be about double the amounts noted above (7.9 and 5.7 μμg/day for the survey period), during the three to four month winter low flow period when irrigation is not practiced. This is estimated for average river flows comparable to those of the survey period.

As an example of the effect of river flow, estimates have been made of radium intake for the water year 1955-56, based upon the monthly average flows for that year at the Cedar Hill gaging station of the U. S. Geological Survey. This gage is 2.5 miles north of the State line. These computations were based upon the observed average of 8.0 mg/day of dissolved radium passing Station 5 during the 1958 survey period. The water year 1955-56, while somewhat drier than the average of the years of record, was not extremely so. As may be noted from Table VI, Section II, the average flow at Station 5 for the 1958 survey period was 432 c.f.s.

Table XLIII indicates the monthly average flows and estimated radium intakes for the water year 1955-56 on the basis of 8.0 mg/day of radium passing Station 5. The intake figures would apply directly to raw water users below the State line in New Mexico.

Table XLIII

Estimated Radium Intake, Water Year 1955-56*

Month	Monthly(4) Average Flow at Cedar Hill c.f.s.	Dissolved Radium at State Line µµg/l	Radium Intake, µµg/day
Oct. 1955	195	16.7	36.8
Nov.	201	16.2	35.6
Dec.	221	14.7	32.4
Jan.	216	15.1	33.2
Feb.	216	15.1	33.2
Mar.	404	8.1	17.8
Apr.	728	4.5	9.9
May	2,201	1.5	3.2
June	1,908	1.7	3.8
July	430	7.6	16.7
Aug.	247	13.2	29.1
Sept.	155	21.0	46.2
		Mean:	24.8

*For raw water users near and below the State line; based on consumption of 2.2 liters per day per person, and on 8.0 mg/day of dissolved radium passing State line.

Thus, for a year like 1955-56 raw water users in New Mexico would take in about three times the allowable amount of radium on an annual average basis if the mill waste discharges remained as found in the 1958 summer survey.

Users of treated water at Aztec and Farmington would take in somewhat smaller amounts of radium in a water year like 1955-56. The concentrations during the irrigation season would be only about 47 and 34 percent, respectively, of the value for Station 5, based on the data of Tables XVII and XXV of Section VI (for example, an average radium concentration of 7.6 µµg/l at Station 5 resulted in an average of 3.6 µµg/l in the Aztec treated water, or 47 percent). During the nonirrigation months there would probably be only slight change in the radium concentrations at Aztec and Farmington from the value for the State line. Allowing figures of 75 percent and 60 percent for this purpose, as compared to the 47 and 34 percent noted above, and estimating the irrigation season as May through September, it results that the intake at Aztec and Farmington would be 16 and 13 µµg/day, respectively, in a water year like 1955-56. This would amount to 1.8 and 1.5 times the allowable intake of 8.8 µµg/day.

Thus, the effect of river flow as available dilution must be considered in estimating daily quantities of radium ingested on an annual average basis. For the water year 1955-56 computations have been made using the daily average flows instead of monthly averages, in order to determine whether a significant difference would result. For that year, estimated concentrations of radium were 5 percent higher when using the daily average flows. Hence, it appears that the use of monthly average flows for this purpose are satisfactory.

For purposes of comparison with the foregoing figures, the average radium intake at Durango, whose water supply is taken from the Florida River, is about 0.7 µµg per person per day. This is based upon an average dissolved radium concentration of 0.3 µµg/l, as observed at Station 3 during 1958 (See Table XVII, Section VI). Thus, this population receives only about 8 percent of the allowable radium intake via its water supply. This daily intake should be unaffected by Florida River flows or by irrigation practice in the area.

The foregoing estimates must also be interpreted in terms of various other influencing factors. A large portion of the dissolved radium apparently comes about by virtue of dissolution from the bottom deposits. At any time, depending on recent stream flow history, the amount of undissolved radium in the river bed reservoir may be greater or less than during the 1958 Survey. This would be a function of the duration of low flow periods. In the case of the survey a period of only 6 to 8 weeks of accumulation after the spring flood is involved.

The extended three to four month low flow periods of the winter and of some summers would permit greater accumulations of radium on the river bed. Once deposited it is probable that only some fraction of the radium is flushed by flood flows. Deposited radium-bearing solids thus provide a long term reservoir as a source of dissolved radium in the water. Also, it must be recalled that an expansion of mill capacity from 514 to 700-750 tons of ore per day was planned for the near future. This would, of course, raise the foregoing estimates proportionately if present waste disposal practices continued unchanged. Estimates of radium reduction between the State line and Aztec and Farmington during nonirrigation months will be verified with further data in a later report.

Uranium. Although the uranium concentrations indicated in Section VI are relatively high, in terms of natural uranium content, they are not so in terms of allowable amounts. The MPC for natural uranium in water is 209 mg/l(8), and with the usual factor of 10 applied for general population exposure, 20.9 mg/l. An average of 127 µg/l was observed at Station 5 for the summer of 1958, and this constitutes only about 0.6 percent of the allowable amount.

Strontium. Treated water samples at Aztec and Farmington contained only 1.0 µµc/l. of strontium-90, which is only a little more than 1.0 percent of the allowable amount of 80 µµc/l.

Foods and Milk

Radium. Considerable data are reported in Section VI regarding the radium content of foods grown in the Durango-Farmington area. It has been noted from these data that on the average foods grown with irrigation water taken from the Animas below the mill had about twice the radium content of foods grown using water from above the mill.

In order to estimate the daily intake of radium via the food route the following moderate cost diet for physically active men has been used(24):

Table XLIV

Diet for Physically Active Men

Item	Lbs. per Week
Leafy green vegetables	3.75
Citrus fruits and tomatoes	3.0
Potatoes and Sweet potatoes	3.25
Other vegetables and fruits	4.0
Milk	5.0 qts.
Meat, poultry, fish	3.0
Eggs	7.0 eggs
Dried beans, peas, nuts	0.25
Flour and cereals	3.75
Fats and Oils	1.13
Sugar, Syrups and Preserves	1.13

In using the data of Table XXXV, Section VI, on radium in foods, and the data of Table XLIV, it was necessary to average results for radium and apply the averages to the items in Table XLIV. Leafy green vegetables, and other vegetables and fruits were combined for an intake of 7.75 lbs. per week. An average radium content for all vegetables and fruits was applied to this figure, but excluding potatoes, tomatoes, wheat, oats, and of course alfalfa, which is not consumed directly by humans. Only the data for farms located to use irrigation water taken from below the mill were used, in order to estimate the radium intake for New Mexico farms. Radium concentrations in potatoes, wheat and oats, tomatoes, and milk were used separately as indicated.

In the absence of information for farms downstream from the mill, the radium contents of potatoes and tomatoes from upstream farms have been used, and should be conservative for estimates of downstream exposures. More information regarding the radium content of foods will be available in a later report. Table XLV indicates the results of these computations. All radiums except for milk were converted to µµg/lb.

As may be seen, it is estimated that about 4.4 µµg per day of radium are ingested on the average by people of the area south of the mill who consume crops grown on these local farms. This constitutes 50 percent of the total daily allowable intake of radium. Nor does it include all foods, as is evident from the table. It assumes, rather, essentially no radium intake with

Table XLV

Radium Intake with Foods and Milk*

Item	Lbs. per Day Consumed	Radium, µµg/lb.	Radium Intake µµg/day
Leafy green vegetab[illegible]	0.54	1.91	1.0
Citrus fruits and tomatoes	0.43	0.5**	0.2
Potatoes	0.47	0.4**	0.2
Other vegetables and fruits	0.57	1.91	1.1
Milk	0.71 qt.	0.4 µµg/qt**	0.3
Meat, poultry, fish	0.43	-	-
Eggs	1 egg	-	-
Dried beans, peas, nuts	0.036	-	-
Flour and cereals	0.54	3.0	1.6
Fats and oils	0.16	-	-
Sugar, syrups, preserves	0.16	-	-
		Total:	4.4

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*Farms located downstream from the mill.

**Single value used; Potatoes and tomatoes representative of upstream farms.

meat, poultry, fish, eggs, dried beans, peas, and nuts, fats and oils, or sugar, syrups and preserves. While the radium content of many of these items may be small, it is not necessarily so. For example, the data of Table XXXV indicate relatively high radium concentrations in alfalfa. This radium, ingested by cattle, may find its way to some degree into the meat, milk, and derived dairy products consumed by humans. Preserves made from locally grown fruits would have some radium based on the data of Table XXXV. Potatoes and tomatoes grown on downstream farms may have more radium than the amount used here. As for the case of radium in water, the foregoing estimate of 4.4 μμg/day should be increased somewhat for planned expansion of the capacity of the uranium mill.

Strontium. Similar computations have been made for the same diet based upon the strontium-90 concentrations noted in Table XXXV, except that the high concentration for lettuce (965 μμc/kg) was excluded from the averages. The average concentration of strontium-90 in milk from Table XXXII was used. The concentration averages used were, specifically, 48 μμc/kg for vegetables and fruits, 4.1 μμc/kg for potatoes, 31 μμc/kg for flour and cereals, 6.4 μμc/kg for tomatoes, and 5.4 μμc/l for milk. The results of these computations indicated on the average a daily intake of 39 μμc of strontium-90, or 22 percent of the allowable daily intake of 176 μμc. Again, no estimate has been made for strontium intake by consumption of meat, poultry and fish, eggs, dried beans, peas and nuts, fats and oils, or sugar, syrups and preserves. Hence the estimated strontium-90 intake is probably conservative. As has been noted in Section VI, the minnow samples did have some strontium-90 (1.4 μμc per gram of ash), but in as much as this included the bones and any soil in the gut, it has been omitted.

For purposes of comparison estimates have also been made of radium intake from milk and foods for people consuming crops raised upstream from the mill. Computations similar to the foregoing, but based upon average radium data for the upstream farms, indicate an average daily radium intake of 2.5 μμg. The strontium-90 intake is probably about the same as that for downstream farms, or 39 μμc/day.

Other Sources of Exposure

Certain other sources of internal radiation exposure exist in the Durango-Farmington area, but were not susceptible to measurement or analysis at the time of survey. No attempt was made to estimate the occupational exposure of workers at the uranium mill. No measurements were made to evaluate the effects of air pollution in the vicinity of the mill. Other bone-seeking radio-isotopes occur also in fallout, but no attempt was made to measure their concentrations, as it was believed their effect would be negligible compared to radium and strontium-90. As has already been noted, the effects of watering stock in the Animas River or its irrigation ditches, together with the use of radium-bearing alfalfa, has been neglected as a source of internal radiation exposure, as has been any effect of grazing cattle on irrigated land except insofar as this would place strontium-90 in the milk. Many or most of these additional sources of exposure may well be relatively minor. No estimates have been made, either, of any special exposure of the boys observed swimming and fishing in the Animas just below and opposite the mill.

Discussion

All of the foregoing estimates of internal radiation exposure have been on the basis of averages for the New Mexico area under consideration. It must, therefore, be borne in mind that individuals and individual families may take in more or less radium and strontium, depending upon circumstances. Some may drink more water than others and some eat more meat or cabbage than others. A farm family consuming largely its own crops may ingest more or less radium, depending on its diet and location on the River. Bearing this in mind, it must be concluded that the figures for intake of radium and strontium-90 are only averages. The figures may be either lower or higher in individual cases by a significant factor. In this sense, the estimated figures are conservative, as well as in the sense of other sources of exposure that have been neglected.

Finally, estimates of human radiation exposure for the area must be considered in the light of plans for development of the river basin. As has been noted earlier, the proposed Animas-La Plata Diversion project and the Navajo Dam on the San Juan River will divert flows from the rivers involved, leaving only minimum flows to satisfy existing water rights and maintain fish life. The Animas-La Plata project would thus materially reduce available dilution at Durango, and the Navajo Dam would do the same at Shiprock. This would have the effect of raising the levels of radiation exposure below Durango.

Summary

It has been estimated that as of conditions at the time of the survey in 1958, raw water users in New Mexico, and users of treated water at Aztec and Farmington ingested an average of 16.7, 7.9, and 5.7 μμg/day of radium, respectively. Added to this, on the average for consumers of locally grown crops, 4.4 μμg/day of radium were ingested, and about 39 μμc/day of strontium-90. In terms of allowable exposures, then, the totals would be 21.1, 12.3, and 10.1 μμg/day of radium, or 2.40, 1.40, and 1.15 times the allowable amount of radium of 8.8 μμg/day. The strontium-90 amounts to 0.22 times its allowable amount. Hence, in terms of total measured exposure, the users of raw river water, Aztec treated water, and Farmington treated water were ingesting sufficient radio-active material to receive 2.6, 1.6, and 1.4 times the allowable amount of internal radiation exposure, at the time of the survey. Based upon irrigation practice in the area, upon planned expansion of milling capacity, and upon the existence of other sources of exposure that have been neglected, it is probable that these estimates of exposure, if used as annual averages, would be conservative.

The foregoing figures are indicated in Table XLVI, together with estimates on an annual average basis, and estimates based upon increased ore processing capacity at the mill. Annual average figures were obtained by projecting the 1958 survey data to a water year such as occurred in 1955-56. Estimates for increased ore processing capacity were made on the basis of a direct proportionate increase in radium water concentrations. Specifically, if the capacity increases to 700 tons per day from 514, then the water concentrations of radium are estimated at 1.36 times those found in 1958. Each item is given in terms of a fraction of the allowable amount. Although the radium concentrations in irrigation water, and hence probably in local foods, would be higher in a water year like 1955-56, no allowance for this effect on foods has been made in the computations for Table XLVI.

Thus, as shown by the Table, in a water year like 1955-56, and based on concentrations of radium as observed in 1958, raw water users below the State line would ingest 3.6 times the allowable amount of radio-active material. Treated water users at Aztec and Farmington, New Mexico, would ingest about 2.6 and 2.2 times the allowable amount, respectively. Under these conditions, but with mill capacity increased to 700 tons per day, the figures would become 4.6, 3.2 and 2.7 times the allowable amount of radium and strontium-90 combined, for New Mexico users of raw water, treated water at Aztec and treated water at Farmington, respectively.

Table XLVI

Summary of Estimated Exposures in Fractions of the Allowable Amount

	As found in 1958 Survey				In a Water Year like 1955-56			
	Durango	Raw	Aztec	Farm.	Durango	Raw	Aztec	Farm.
Radium in Water	0.08	1.90	0.90	0.65	0.08	2.82	1.82	1.46
Strontium-90 in Water	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Radium in Food and Milk	0.28	0.50	0.50	0.50	0.28	0.50*	0.50*	0.50*
Strontium-90 in Food and Milk	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Totals:	0.59	2.63	1.63	1.38	0.59	3.55	2.55	2.19
Increase due to planned mill capacity expansion **	0.00	0.69	0.33	0.24	0.00	1.02	0.66	0.53
Totals:	0.59	3.32	1.96	1.62	0.59	4.57	3.21	2.72

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* No increase included for higher radium concentrations in irrigation water.

** Increase of 36 per cent in water radium concentrations for planned mill expansion from 514 to 700 tons of ore per day.

SECTION IX

SUMMARY AND CONCLUSIONS

Background

During the summer of 1958, for a two month period extending to mid-September, a survey of pollution problems of the interstate waters of the Animas River was performed. The results of this survey have been reported in previous Sections. Routine sampling was continued into the first half of 1959, and the results of these later samples will be given in a subsequent report. The objectives of the survey were to evaluate the internal radiation exposure to radium and strontium in the Durango-Farmington area, the portion of this exposure resulting from waste discharges from the Vanadium Corporation of America uranium refinery at Durango, Colorado, and the interstate pollutional aspects of these waste discharges.

The survey included a wide variety of environmental samples, including river waters, muds and biota, treated water supplies, foods grown locally using irrigation water from the Animas River, locally produced milk, precipitation and effluents from the uranium ore refinery. Studies of the toxicity of the mill effluents to the aquatic biota were also carried out.

Water Uses. The Animas River from Durango, Colorado, to Farmington, New Mexico, a distance of some 60 river miles, is used for a variety of purposes. It serves as a source of water supply for the communities of Axtec and Farmington, New Mexico, with a combined population of about 28,000 people. It is used in the raw state as a water supply for approximately 100 people in Colorado and 1,845 people in New Mexico.

Below Durango, the Animas provides water also for the irrigation of some 26,000 acres of cropland during the growing season. A wide variety of crops, including root and leaf vegetables, cereals and grains, and fruits is grown in the area. Alfalfa is a major crop. The river is also used for recreational purposes below Durango, including fishing and swimming, and serves for stock watering both directly and via the irrigation ditches. Finally, it is the source of industrial process water for the uranium ore refinery, and carries away the wastes from this mill, as well as from the City of Durango and other small sources.

Of the foregoing water uses data is included here regarding water supplies, irrigation and foods, and waste disposal. Only indirect data are provided regarding the stock watering and recreational uses of the stream, except insofar as the chemical toxicity studies provide information regarding the expectancy of normal fish and aquatic insect populations below the mill. A summary of radiation exposure for the area is provided, including the exposure to radium and strontium-90 in water, milk, and some foods.

Results

Mill Effluents. During the 1958 survey, the Durango mill processed ore for uranium and vanadium recovery at a rate of about 514 tons per day of ore. Two continuous and one intermittent liquid effluents from the uranium mill at Durango were sampled during the survey. All samples were analyzed for gross alpha and beta radioactivity, and selected samples for radium, uranium, and chemical components. These effluents had a combined average flow of about 360 gallons per minute, or 0.8 cubic feet per second during a one-week survey of the mill process. In contrast, over the eight weeks of survey the Animas River flow at Durango ranged from 500 down to 290 cfs on a weekly average basis. Hence, during the survey the combined mill effluents received dilution by a factor of from 360 to 620 after being mixed with the river water.

The dissolved radium content of the mill waste discharges varied from 44 to 822 μμg/l. The main effluent, including the bulk of the flow, contained 44 to 160 μμg/l. of dissolved radium. Based upon effluent flows, the dissolved radium discharge to the river averaged about 0.30 milligrams per day, with a maximum of about 0.80 milligrams per day. The effluent radium concentrations may be compared with the allowable concentrations specified by the U. S. Atomic Energy Commission for its licensees of 4.0 μμg/l.(10) Dissolved radium in the effluents was somewhat higher than was observed in 1955, when two effluent samples analyzed for radium gave results of 25 and 76 μμg/l.

It has also been estimated that during the 1958 survey the mill discharged to the river an average of 30 to 40 milligrams of radium daily in the undissolved state. This was contained in a daily discharge of about 15 tons of undissolved solids. It amounted to about 7 to 10 per cent of the estimated radium content of the ore received at the mill.

On the basis of analysis of selected mill effluent samples and river samples it has been estimated that on the average the mill discharged in the neighborhood of 200 pounds per day of dissolved uranium to the Animas River.

Studies of the aquatic biota indicated that the mill effluents had a definite chemical toxicity for fish and aquatic insect populations. Sampling of the bottom dwelling aquatic insects, which constitute a basic food for fish, indicated that the Animas above the mill, as well as its tributaries, Lightner Creek and the Florida River, were productive streams having a good variety and population of aquatic organisms. Below the mill the Animas River bottom insect population was greatly reduced in kind and number, to as few as five insects of only one species in three square yards of river bed at a location 2 miles below the mill. Recovery to reasonably normal numbers and kinds of bottom insects did not occur until the river reached a location 15 miles into New Mexico, or a distance of about 43 miles below the mill.

Studies of the toxicity of mill effluents to rainbow trout indicated that Animas River flows in the neighborhood of 600 cfs at Durango would be required to protect the fish and insect populations from harm. These studies included several process waste streams as well as the direct effluents, and indicated that wastes from the solvent extraction process in the mill were the most toxic component of the direct effluents. As has been noted, flows at Durango in the Animas dropped to 290 cfs during the survey, with resulting observed elimination of most bottom insect species immediately below the mill and great reduction of insect populations for 43 miles.

River Samples. The Animas River was sampled at five basic stations over a distance of about 60 miles, from a location above the Durango mill to Farmington, New Mexico, where it joins the San Juan River. Over the eight weeks of survey, dissolved radium in the river water averaged 12.6, 7.2, 7.6, and 2.9 µµg/l. at locations 2, 23, 28, and 59 miles below the mill. Natural radium content of the river above the mill averaged 0.6 µµg/l., and 0.3 µµg/l. for the two tributaries, Lightner Creek and the Florida River. At the Colorado-New Mexico boundary line the average was 7.6 µµg/l. of dissolved radium. The raw water supplies of Aztec and Farmington, New Mexico, had averages of 3.4 and 2.8 µµg/l. of dissolved radium, while treated waters averaged 3.6 and 2.6 µµg/l., respectively. Thus, conventional water treatment at these two communities did not remove dissolved radium from the water. To the contrary, the filter sands at the Aztec water treatment plant contained more radium by a factor of 6 than those at Farmington, and the data show a slight gain in dissolved radium in the treated water as against raw water at Aztec. Thus, it appears that the accumulation of undissolved radium on the sand filters resulted in some added amount of dissolved radium in the treated water at Aztec.

During the survey raw water users in New Mexico were exposed to radium concentrations of 7.6 µµg/l. on the average. This and the foregoing figures may be compared to the allowable concentration of 4.0 μμg/l.(8)(9)

Computations indicated about 11.5 milligrams per day of dissolved radium passing a river location 2 miles below the mill, and 8.0 milligrams per day passing the State line 28 miles downstream. Above the mill about 0.5 milligrams per day were found. This gain of 11.0 milligrams per day was not observed in the mill effluents as dissolved radium. However, as has been noted, some 30 to 40 milligrams per day were discharged in the undissolved state. This formed a reservoir of undissolved radium on the river bed in the vicinity of the mill, and this reservoir served as a source of dissolved radium in the river water. That radium does dissolve out of such muds was verified in a series of laboratory experiments. River mud samples were only selectively analyzed for radium. They indicated a natural background radium content of 1.7 μμg/l. of radium per gram of dry mud. Below the mill, the radium content of muds was about 115, 48, 21, and 4 μμg/gm. at locations 2, 23, 28, and 59 miles below the mill.

Radium is a long-lived material (it has a 1,620 year half-life) and such river mud deposits form a long-term reservoir from which the water can be contaminated. The extent to which floods will scour and flush such deposits depends on local topographic and hydrological features, and is not definitely known for the Animas near Durango. The data presented here represents accumulation of radium in the muds, and resulting water contamination, for a period of only 6 to 8 weeks following a major spring flood on the river. It seems probable that only a portion of the radium reservoir was removed by this flood.

The aquatic algae at a location 2 miles below the mill showed a radium content of nearly 100 times the natural amount. This diminished progressively to 30 times the natural content at the State line and about 5 times the natural radium at Farmington. The aquatic insects showed a similar picture. Fish were not analyzed for radium, but will be included in a later report.

Vegetable and crop samples from farms using Animas River irrigation water indicated some radium contamination. Detailed results are presented in Section VI. In general, crops raised on farms using river water taken from below the mill (including primarily New Mexico farms) contained about twice the radium as did crops raised on farms north of Durango using the river water before it received the mill effluents. About half of the crop samples taken from the downstream farms contained 4.0 μμg of radium per kilogram of live material or more. Samples of irrigation water generally reflected the radium content of the Animas River at the point of irrigation diversion.

Samples of river water analyzed for dissolved uranium indicated from 200 to 400 pounds per day of dissolved uranium passing stations 2 miles and 28 miles below the mill, with no detectable difference between the locations. A later set of instantaneous samples (April 1959) indicated 84 lbs/day 2 miles below the mill and 190 lbs/day at the State line, 28 miles downstream.

The strontium-90 content of selected river water samples averaged 0.8 μμc/l. Water samples at Aztec and Farmington contained about 1.6 and 1.0 μμc/l. of strontium-90, respectively, for raw and treated water. River muds and topsoil samples contained about 0.5 μμc of strontium-90 per gram of ash. Several algae and aquatic insect samples showed about 0.4 μμc of strontium-90 per gram of ash.

Milk samples from the area, taken on a monthly basis, contained an average of 5.4 μμc of strontium-90 per liter. Details as to other radioactive constituents are shown in Section VI. Precipitation samples from Durango and Farmington during the 1958 survey contained from 0.7 to 23.0 μμc/l. of strontium-90. Crop samples from the area contained from 2.5 to 315 μμc of strontium-90 per kilogram of live material, excluding a single lettuce sample which was higher. Details regarding the strontium-90 content of foods are given in Section VI.

Analysis of river water samples indicated no serious bacteriological pollution problem below Durango, Colorado, except possibly insofar as the Animas River water may be used in the raw state for domestic purposes. The dissolved oxygen content of the river water was adequate to support aquatic life, remaining near saturation until the river reached Farmington. Biochemical oxygen demands of the river water above Farmington were usual in the course of the reaction, and were low enough so as not to depress the dissolved oxygen of the river.

In reviewing all of the foregoing results, it should be borne in mind that during the 1958 survey the Vanadium Corporation of America ore refinery at Durango was processing about 514 tons per day of ore. Plans to increase this capacity to about 700 tons/day have been announced by mill officials. In that event, some of the foregoing data should be increased proportionately for purposes of estimating the extent of future pollution problems. Also, the proposed upstream flow regulation by the Animas-LaPlata Diversion project would materially reduce available dilution at Durango.

Internal Radiation Exposure

The foregoing information regarding the radioactivity content of environmental samples has been interpreted in terms of internal radiation exposure for the area under consideration. As has been indicated earlier, interest is in the total daily intake of radioactive materials of all kinds and by all paths, rather than solely in water concentrations. Thus, the intake of radium in water, milk and other foods must be summed up to obtain a daily intake figure. In addition, strontium-90 is also a bone-seeker, and its presence and effects must be considered together with radium.

Based upon the MPC's for radium and for strontium-90,(8)(9) the allowable daily intake of each in the absence of the other is 8.8 μμg for radium and 176 μμc for strontium-90. The observed and estimated daily intakes have been computed in terms of decimal fractions of the allowable amounts of radium and strontium-90 on an individual basis for water, milk and foods. Thus, to estimate total internal exposure in terms of the allowable amount, it is only necessary to sum the individual decimal fractions.

Several categories of internal exposure have been observed, including consumers of raw water in New Mexico, of treated water at Aztec and Farmington, New Mexico, of treated water at Durango, Colorado, and of foods raised using Animas River irrigation water taken from the river above and below the uranium mill. River flows during the survey covered only a two month period, and were somewhat higher than in a number of the years of record. Hence, the radiation exposure figures have also been projected to a year in which flows like those of the 1955-56 water year occur, in order to provide estimates of annual average exposure. Also, estimates have been projected to encompass a planned expansion of ore processing capacity at the mill from the 514 tons per day observed in 1958 to 700 tons per day, as planned.

On these bases, and on the basis of observed radium and strontium-90 concentrations, it has been estimated that on the average persons in the Durango area, using crops raised north of the uranium mill with uncontaminated river irrigation water, receive about 60 per cent of the total allowable daily intake of radium and strontium-90, combined. Of this total, about 80 per cent is ingested radium and strontium-90 in food and milk, and the remainder represents largely naturally occurring radium in the water supply. These figures would not be affected by the planned mill expansion, nor are they a function of flow in the Animas.

For flows as observed during the 1958 survey it is estimated that on the average raw water users in New Mexico ingested 1.9 times the allowable daily intake of radium via their water supply. In addition, if they consumed locally raised crops, they ingested about 0.5 times the allowable daily radium intake and 0.2 times the allowable daily strontium-90 intake via their food supply. Summing up, then, they ingested a total of about 2.6 times the combined allowable daily intake of radium and strontium-90. On the basis of river flows for the water year 1955-56, this total figure on an annual average basis becomes about 3.6 times the allowable amount, the difference being due to increased radium ingestion via the raw river water. Should the proposed mill expansion become an actuality, with existing waste disposal practices remaining unchanged, increased radium concentrations in the water should be expected. The total combined intake of radium and strontium-90 in water, milk and food would then be about 4.6 times the allowable amount.

It has further been estimated that users of treated water in Aztec and Farmington, New Mexico, were ingesting on the average about 1.6 and 1.4 times, respectively, at each location, the allowable combined daily intake of radium and strontium-90 during the survey period. This assumes also the consumption of crops grown below the mill. Projected to a water year like 1955-56, and allowing for local irrigation practice, these total figures become about 2.6 and 2.2 times the allowable daily intake. On the basis of increased mill capacity and no change in waste disposal practice they become about 3.2 and 2.7 times the allowable amount.

Details of the foregoing figures are given in Section VIII. On the basis of available data the figures are believed to be reasonably conservative.

It must be emphasized that the figures regarding internal radiation exposure are averages for the area, and must be interpreted in that sense. It is probable, therefore, that significant deviations from them occur as far as individuals and individual families are concerned. Thus some individuals may ingest less and others more radioactive material than the averages indicate, depending upon individual daily intake of water and milk, the types and quantities of food consumed, specific location of the irrigated farm, and other individual and local differences.

It should also be recalled, in interpreting the results presented here, that the allowable daily intake of radioactive material refers to that amount which can be ingested continuously over a lifetime without producing any readily detectable biological damage. Hence, ingestion of any particular radioisotope in amounts somewhat higher than the allowable for relatively brief periods of time may not result in undue harm. On the other hand, the cautionary note introduced by the National Committee on Radiation Protection(8) bears repeating:

> "Because of the many uncertainties involved, this Committee recommends that every effort be made to keep the concentrations of radioisotopes in air and water and in the body to a minimum. The goal should be no radioactive contamination of air and water and of the body if it can be accomplished with reasonable effort and expense. If such a goal cannot be attained, the average operating levels should be kept as far below these recommended values as possible, and not above them for any extended periods of time."

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